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Global Acoustic Mapping of Ocean Temperatures

GAMOT

Woods Hole Oceanographic Institution
The Pennsylvania State University
Naval Research Laboratory–Stennis
The Florida State University
University of Alaska
University of Texas at Austin

QUARTERLY PROGRESS REPORT

July-September 1993

GAMOT

October 15, 1993

Dr. Ralph Alewine
Advanced Research Projects Agency
3701 North Fairfax Drive
Arlington, VA 22203-1714

Dear Dr. Alewine,

The attached report fulfills the second quarterly progress report requirement for the period from July 1, 1993 to September 30, 1993 as contained in the ARPA Grant No: MDA972-93-1-0004 entitled "Real Time System for Practical Acoustic Monitoring of Global Ocean Temperature" issued by the Contracts Management Office. The United States Government has a royalty-free license throughout the world in all copy rightable material contained herein. This report is approved for unlimited distribution and public release. Additional copies of this report will be mailed to the distribution list contained in Attachment Number 2 of the Grant. This report was delivered to Mr. E. Craig of RPI, Inc. for further delivery to you.

Financial status reports will be submitted separately from this report. Woods Hole Oceanographic Institution, as the Grantee, will submit all financial reports directly to you.

The information contained in this report represents the inputs and opinions of the entire GAMOT team; Woods Hole Oceanographic Institution, the Pennsylvania State University, the Applied Research Laboratory, the Florida State University, University of Alaska, University of Texas at Austin and NRL-Stennis. If this report generates any questions, please do not hesitate to direct your questions or comments to the Principal Investigators or the Program Manager.

John L. Spiesberger	Daniel E. Frye	John M. Kenny
Principal Investigator	Principle Investigator	Program Manager
WHOI/PSU	WHOI	ARL

October 15, 1993

GAMOT EXECUTIVE SUMMARY

Work continues on all GAMOT Tasks as described in ARPA Grant No: MDA972-93-1-0004 and remains on schedule with the exception of Tasks C and D. Task C work is behind schedule and there will be a delay in the initial deployment of the operational SSARs of approximately six weeks. Task D, the autonomous mooring, is behind schedule and the total delay cannot be calculated until the impact of the increased scope of Task D, which now includes procurement of a 70 Hz source , can be determined.

• **Task A.** The success of ray theory in identifying multipaths arrivals at basin scales (3000 km) was demonstrated this quarter. GAMOT scientists at Penn State worked with Dr. Tappert to develop a Parabolic Equation suitable for predicting accurate travel times of multipaths at frequencies near 70 Hz. This work is in progress. Programs were developed to compute acoustic travel times through ocean models run by O'Brien, Johnson and Hurlburt. These predictions are being compared to Spiesberger's global warming feasibility experiments conducted in the 1980's. Ray traces for the basin scale tomography experiment conducted by Spiesberger in the northeast Pacific in 1987 have begun. These ray traces will be used to analyze the seasonal signals present in these data between three moored sources and many Navy SOSUS stations. The change to the source code announced in August necessitated the development of new signal processing software, which will require approximately 16 man weeks of new work. This additional work will result in a six weeks delay of the first deployment of the operational SSARs.

• **Task B.** The Task B tasks and deliverables are on schedule. Remote forced NE Pacific (NEP) model runs have been completed for 1961 - 1991 driven by equatorial Kelvin waves. Rossby waves propagating off the coast are shown to significantly alter acoustic travel times. This is demonstrated by estimating the travel time anomalies along great circle paths from an acoustic source near Hawaii to receivers along the western coast of North America. Travel time anomaly due to variations in upper layer thickness are comparable to actual observations (Spiesberger, J. L., and Metzger, K., Basin-scale tomography: a new tool for studying weather and climate, J. Geophy. Res. 96, 4869-4889).

• **Task C.** All elements of the SSAR development are underway and on schedule. The initial SSAR prototype test deployment was conducted in September. A follow-on test of the Standard design followed by release of the prototype for long term evaluation is scheduled for the first week in November. Laboratory testing of test hose sections is underway at Tension Member Technology. Analysis of prototype test data from the sea test is underway. Final mechanical and electrical designs are in process and on schedule.

• **Task D.** On October 15, ARPA directed the GAMOT Principal Investigators to submit a proposal to procure a 70 Hz source and increase the scope of Task D and gave the following guidelines:

- the frequency of the source will be 70 Hz.
- the schedule could be extended to accommodate the additional engineering and source procurement lead time.
- consider both m-sequence and FM coding sources.
- initially a dual design study could be undertaken.
- the proposal should contain go/no-go milestone decision points to ensure effective funding control.
- more than one option for each coding source may be submitted along with recommendations to the best course of action to follow.

The proposal will be completed in January 1994 and submitted to ARPA for approval.

• **Meetings.** GAMOT hosted the ARPA Program Review at WHOI on 16 and 17 September, 1993. The second Executive Committee meeting was held on October 15 in Washington DC. An Ocean Modeling meeting was conducted by Dr. J. O'Brien on October 8 at Florida State University. The next Program Review will be hosted by Dr. O'Brien and GAMOT at Florida State University on March 18, 1994.

• **Outside Interest.** GAMOT's program continues to receive press interest, including articles in *Science* and *Mechanical Engineering*. During this quarter, the status of the program was briefed to the Chief of Naval Research, the Commander, Naval Oceanography Command, the Director of NOAA, the Deputy Assistant Secretary of the Navy for ASW, and the Director of Defense Research & Engineering.

• **Issues and Concerns.** In the previous quarterly report two issues were addressed:

- Acoustic interaction of cabled sources with the bottom slope, and
- Identification of a source for the autonomous mooring.

These issues have not been resolved and their current status is reported. There are no new issues.

TASK A
TOMOGRAPHIC DATA ANALYSIS

All Task A work is on schedule.

GAMOT demonstrated the first successful use of any acoustic model to identify acoustic multipaths over basin scales in the ocean (Spiesberger, J. L., Terray, G., and Prada, Successful modeling of acoustic multipaths at 3000 km distance in the northeast Pacific, submitted to J. Acous. Soc. Am., 1993). This is the furthest distance over which multipaths have been unambiguously identified. The multipaths were transmitted from a 250 Hz source and received at a Navy SOSUS station in 1987. This model was based on the program ZRAY (Bowlin, J. B., Spiesberger, J. L., Duda, T. F., and Freitag, L. E., Ocean acoustic ray-tracing software RAY Woods Hole Oceanographic Technical Report, WHOI-93-10, 1993) and is a particularly successful implementation of ray theory.

We began work with Dr. Fred Tappert to determine if there were any approximations for the acoustic wave equation which would yield times of flight to within 0.02 s near 70 Hz. Classical ray theory is too inaccurate for estimating climatic temperature variations in the ocean at 70 Hz. (Boden, L., Bowlin, J., and Spiesberger, J. L., Time domain analysis of normal mode, parabolic, and eikonal solutions of the wave equation, J. Acous. Soc. Am., 90, 954-958, 1991). This work is focusing on parabolic approximations.

We developed computer algorithms to estimate the acoustic travel times of multipaths through ocean models developed by Jim O'Brien and Mark Johnson. We find that Rossby waves can modulate the travel times of acoustic multipaths by the same order of magnitude as observed from the KANEOHE source experiment. These Rossby waves are generated from el nino's. Spiesberger presented an overview of how acoustic travel times can be computed from these class of ocean models at the modeling workshop presented at Florida State University in October 1993. This workshop was hosted by Jim O'Brien.

We began analysis of the acoustic multipaths measured in 1987 between three 250 Hz sources and the Navy's SOSUS stations. In particular, we began tracing rays with ZRAY so that we can understand how the sound traveled between the source and each receiver. This work forms the starting points for analyzing the annual cycle of warming and cooling in the northeast Pacific over basin scales.

Figure:
Fig. 1 Task A Schedule

NUM	TASK A	Start Date	Finish Date
A.1	ESTIMATE IMPROVED RESOLUTION FROM SSAR BY NUMERICAL SIMULATION	1/15/94	1/15/95
A.2	DETERMINE THE OPTIMUM :		
	SSAR ARRAY DEPTH	5/1/93	6/30/93
	SOURCE LOCATION AND DEPTH	5/1/93	11/30/93
A.3	ESTIMATE THE INFLUENCE OF FREQ, INCLINATION, DISTANCE AND SVP ON MULTIPATH STABILITY	5/1/93	6/30/95
A.4	DEVELOP ALGORITHMS AND COMPUTATIONS WHICH:		
	DO NOT GENERATE EXTRANEOUS EIGEN RAYS	5/1/93	5/15/93
	CALC LOSS FOR GEOMETRIC RAYS	5/1/93	5/15/93
	CALC LOSS FOR SHADOW ZONES OF CAUSTICS	5/1/93	5/15/93
A.5	INCORPORATE THE RAY TRACE ALGORITHM INTO THE INVERSE PROGRAM	7/15/93	5/15/94
A.6	ASSIMILATE TOMO DATA INTO O'BRIEN OCEAN MODEL	9/15/94	4/1/95
A.7	AUTOMATE THE PROCEDURE TO CHANGE SPATIAL COORDS OF MULTIPATHS DUE TO SEASONAL CYCLE	5/1/93	6/30/95
A.8	DEMO REAL TIME TOMOGRAPHY:		

NUM	TASK A	Start Date	Finish Date	1993									1994												1995						
				A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
	USING DATA FROM SSAR	1/15/95	6/30/95																												
	USING DATA FROM FIXED RCVRS	3/15/95	6/30/95																												
A.9	ANALYSIS OF 1987 TOMO DATA TO DETERMINE SEASONAL CYCLE INFLUENCES ON ACOUSTIC TRAVEL TIMES:																														
	FORWARD PROBLEM	7/15/93	6/30/94																												
	INVERSE PROBLEM	9/15/93	8/30/94																												
A.10	SIMULATION OF OCEAN CLIMATE TEMPS FROM AN O'BRIEN OCEAN MODEL USING SSARS	5/1/94	5/30/95																												

TASK B
OCEAN MODELING

The Task B tasks and deliverables are on schedule. Remote forced NE Pacific (NEP) model runs have been completed for 1961 - 1991 driven by equatorial Kelvin waves. Rossby waves propagating off the coast are shown to significantly alter acoustic travel times. This is demonstrated by estimating the travel time anomalies along great circle paths from an acoustic source at near Hawaii to receivers along the western coast of North America. Travel time anomaly due to variations in upper layer thickness are comparable to actual observations (Spiesberger, J. L., and Metzger, K., Basin-scale tomogr?phy: a new tool for studying weather and climate, J. Geophy. Res. 96, 4869-4889).

Model solutions of the NEP have been completed for four different equatorial inputs: (i) a Kelvin wave with period 1 year and no (flat) bottom topography (figure 1). All other runs have realistic topography. (ii) a Kelvin wave with period 1 year (figure 10); (iii) a Kelvin wave with period four years (figure ?); (iv) the Kelvin wave from the equatorial model (figures 3, 4, 5 and 6). The fifth model run involves the same input as (iv) but with the addition of realistic winds (figures 2, 7, and 8). This run is behind schedule due to nonlinear numerical instability during the 1969 El Nino event. The model has been successfully run 1961- 1968 and we are confident that this problem will be overcome in the near term.

Comparison of (i) and (ii) demonstrate the significant effect topographic interactions play in the evolution of the Rossby waves. The difference between (ii) and (iii) clearly shows the variety of spatial patterns that can be produced with signals with periods scanning only a few years. The last completed run (iv) reveals the inter-annual (and inter-decadal) variations that can occur in the NEP due to coastal Kelvin waves.

Comparison of our model results to observations involves computing travel time anomalies are described in the last quarterly report. Total travel times from acoustic source to receiver along the GC path is estimated using a sound speed estimate (Roed 1993)

$$c = c_o - \beta \, \Delta\rho \, (\alpha \, \Delta)^{-1} \, (h-H)$$

where c_o is the mean sound speed, β is the local derivative of the Coriolis term, $\Delta\rho$ is the density difference between upper and lower layer, α is a thermal expansion coefficient, Δ is a geometric constant, h is the upper layer thickness (ULT), and H is its mean thickness. Travel time is then

$$T = \int c^{-1}\, ds$$

where ds is the segment along the great circle path from source to receiver. All the paths used in this calculation originate near 18.4N, 206.2E. Their final coordinates are:

Path#	latitude	longitude
1	21.2	254.1
2	18.4	206.2
3	24.6	247.7
4	26.5	246.6
5	28.5	245.2
6	30.8	243.7
7	33.2	241.7
8	35.9	238.1
9	40.0	235.4
10	47.1	235.2

Travel times for model runs (ii) through (iv) are shown in figures 11 - 15. A video of the model solution described above has been completed and delivered.

Figures

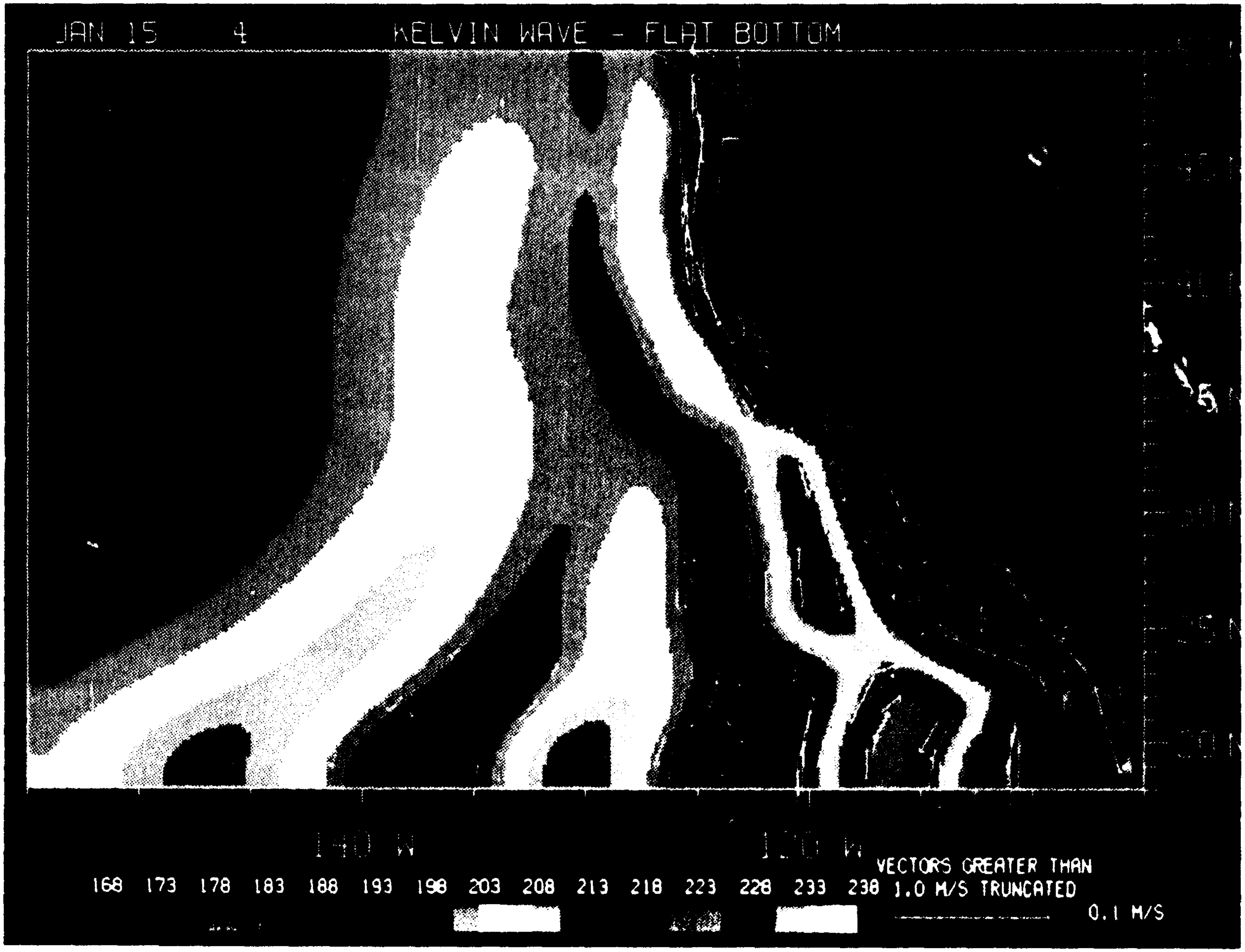


Figure 1. Flat Bottom, Annual Kelvin Wave, 4th Year.

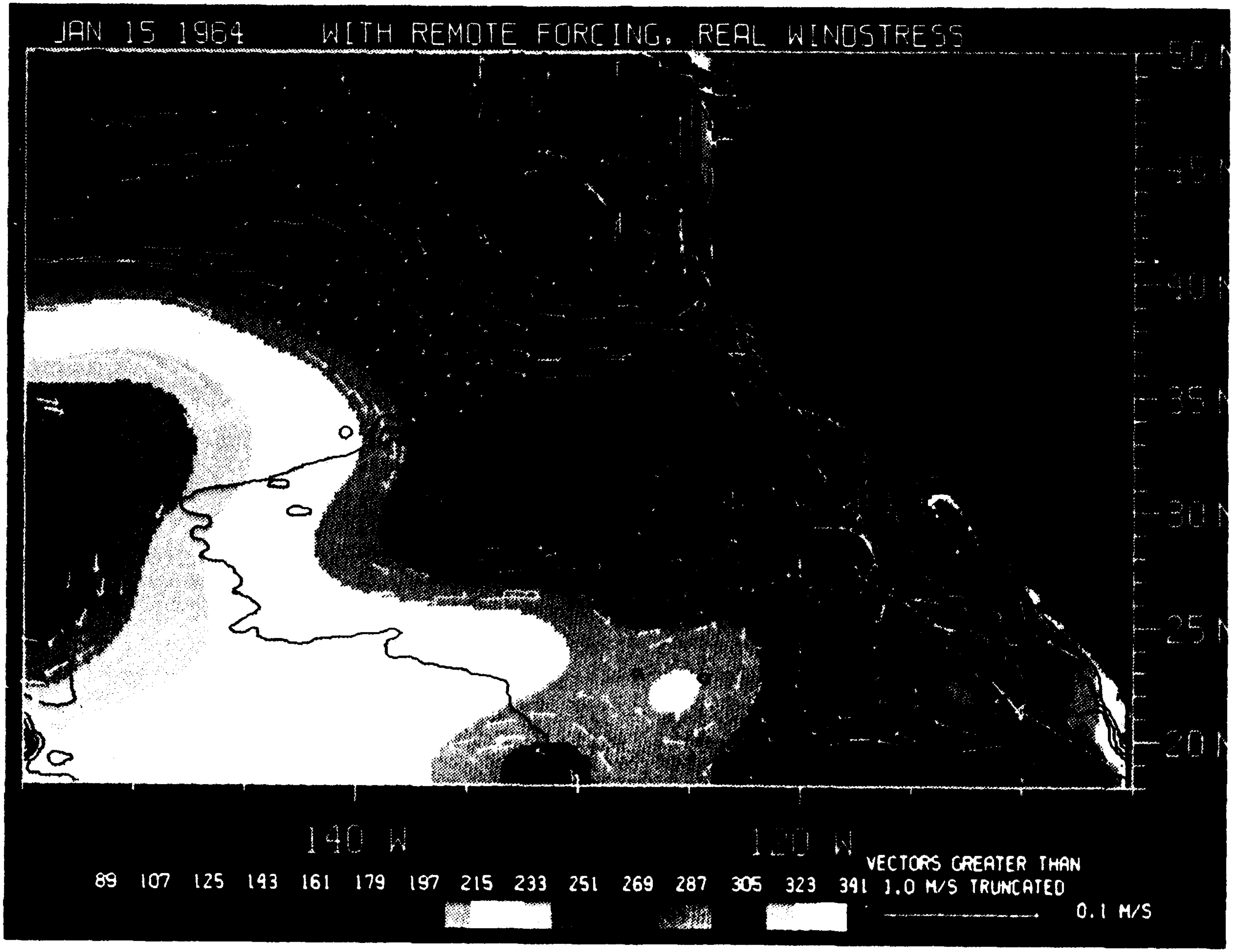


Figure 2. Bumpy Bottom, Wind & Remote, 1964.

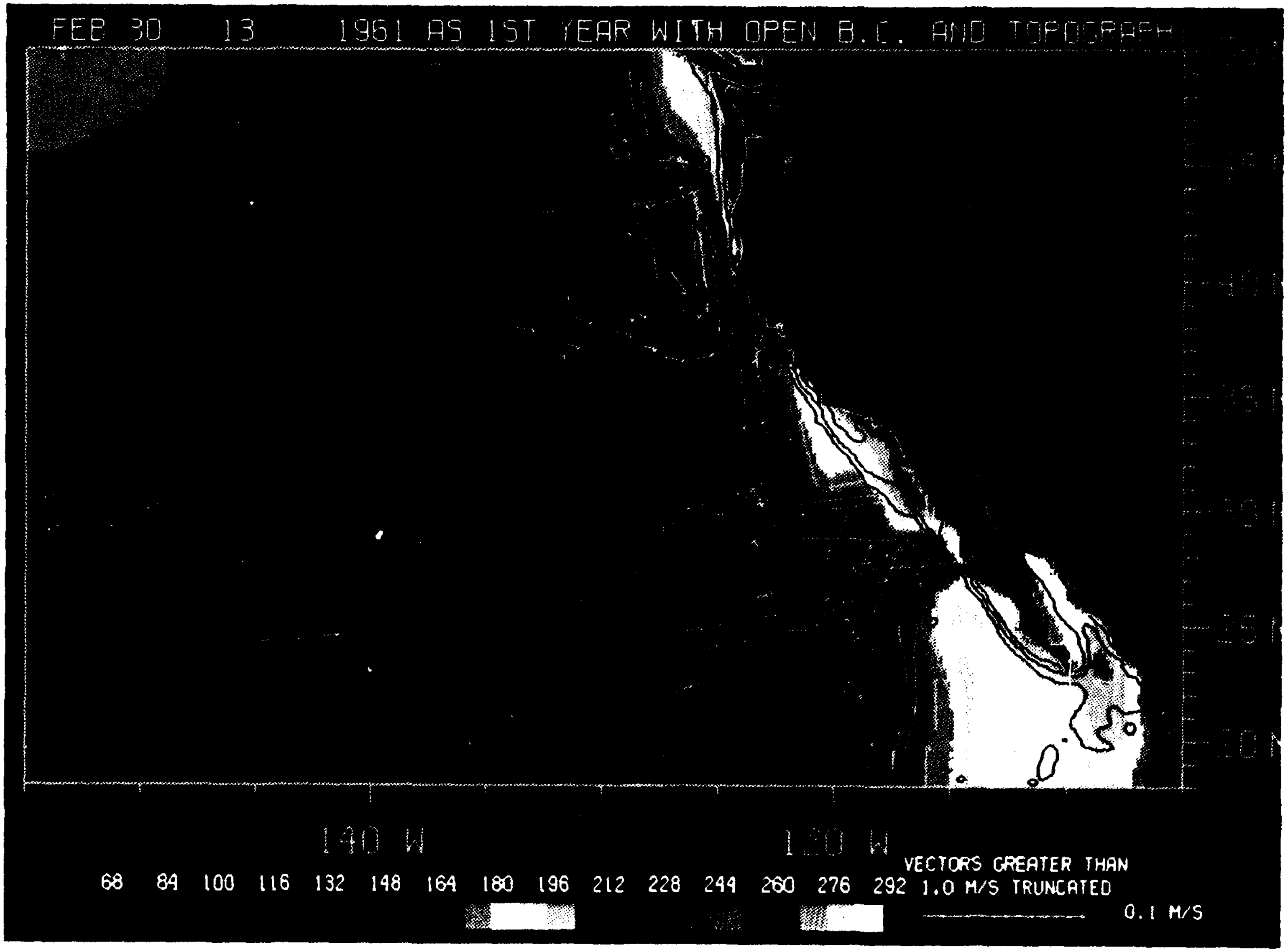


Figure 3. Bumpy Bottom, Remote Forcing & Eddies, 1973.

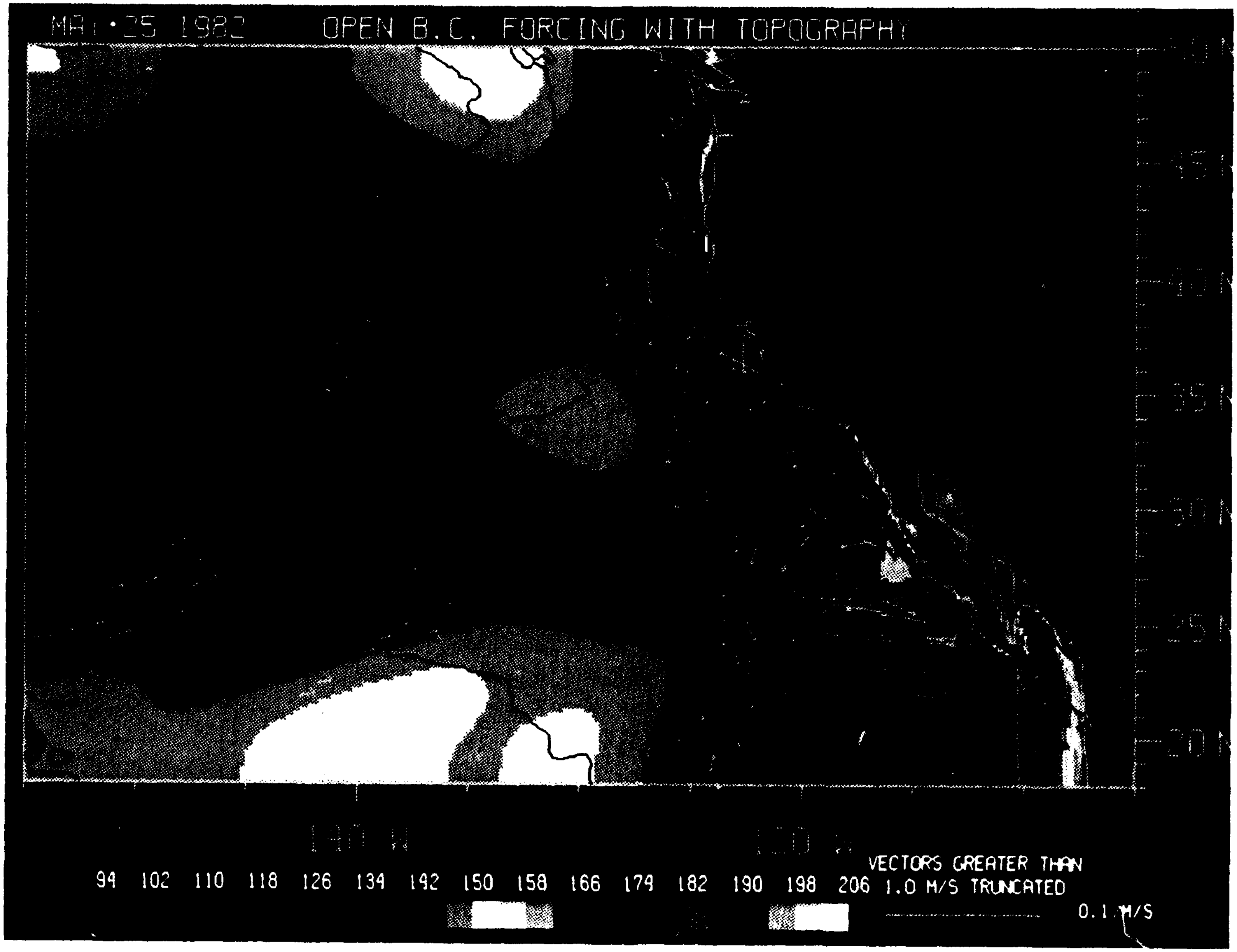


Figure 4. Bumpy Bottom, Remote Forcing & Eddies, 1982.

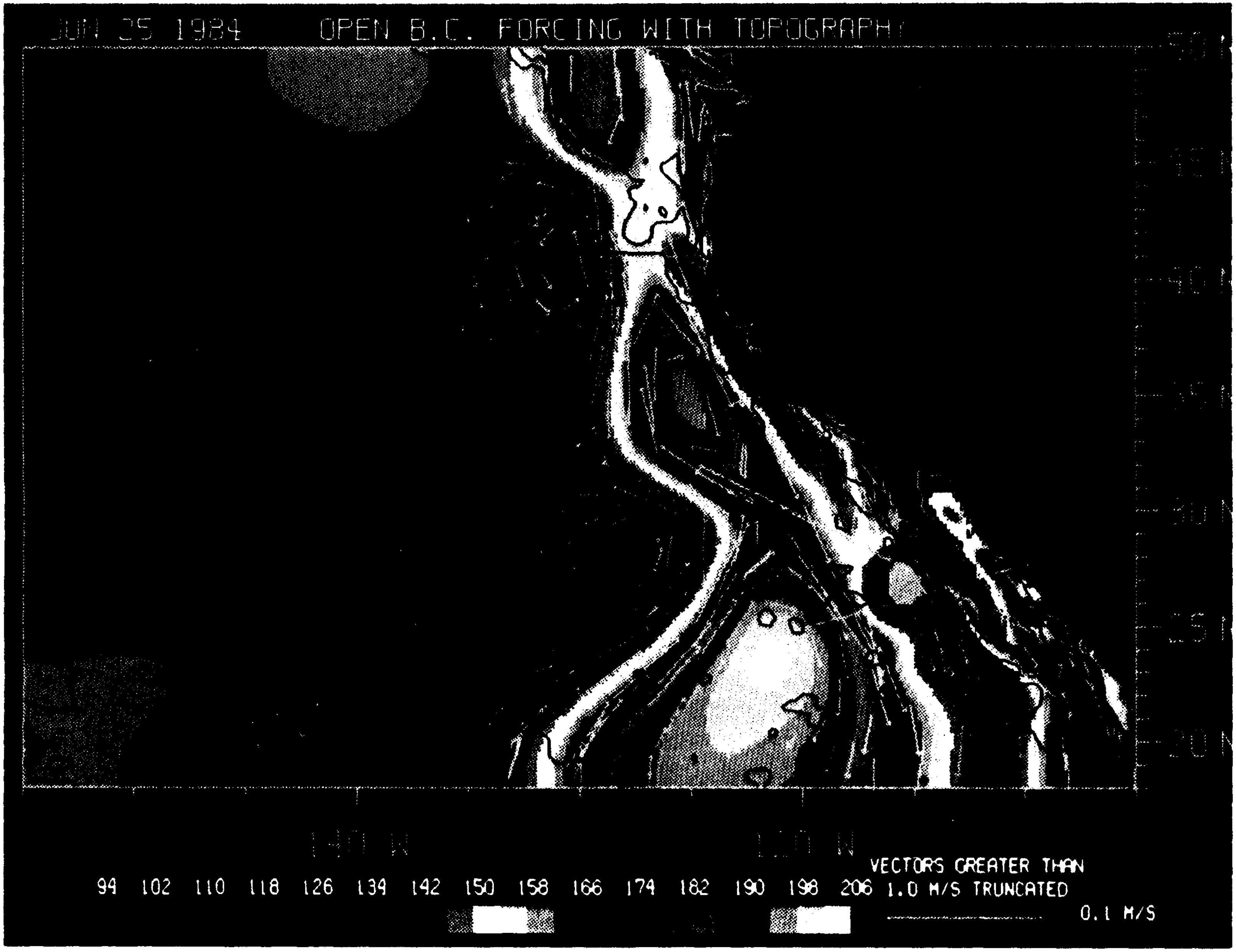


Figure 5. Bumpy Bottom, Remote Forcing & Eddies, 1984.

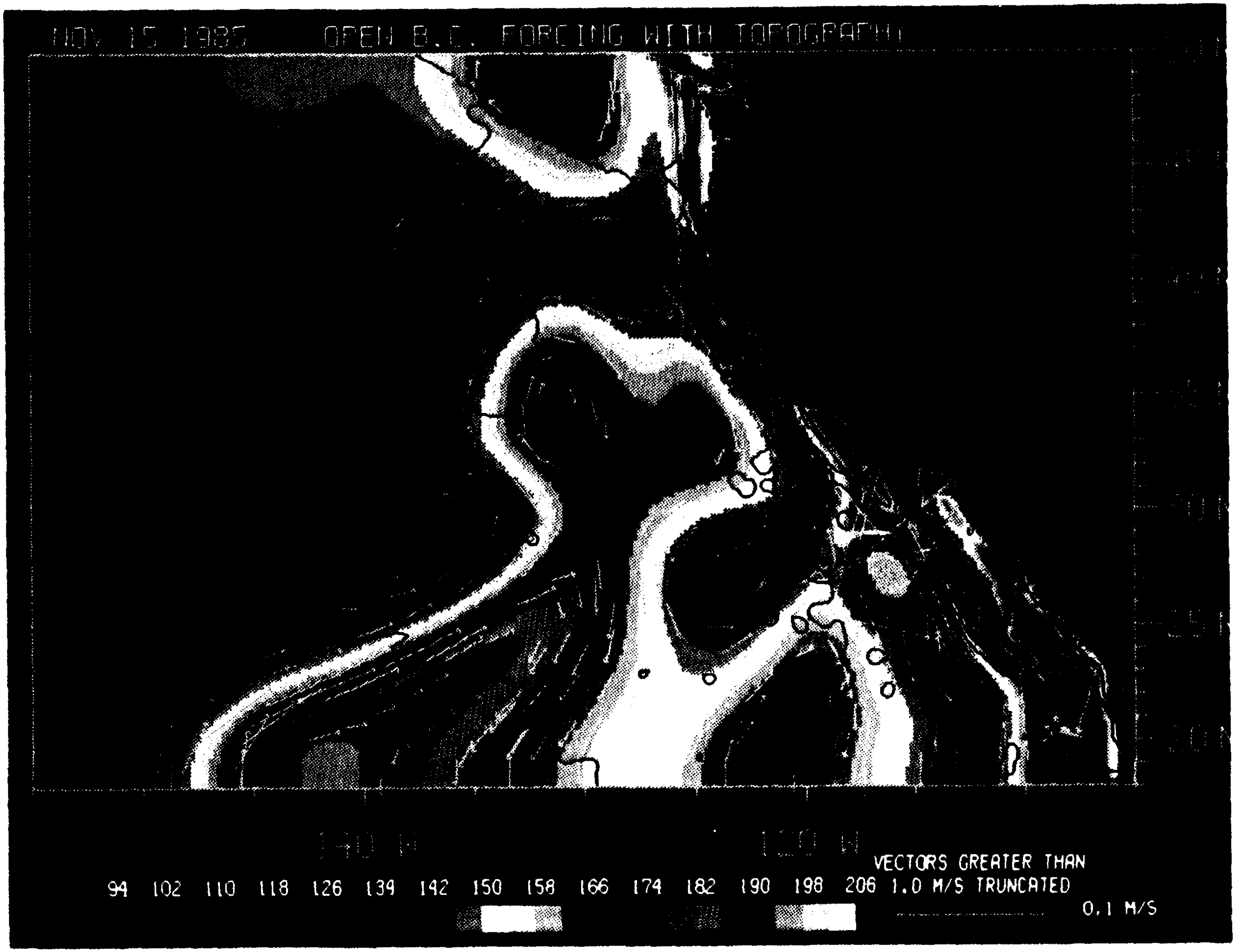


Figure 6. Bumpy Bottom, Remote Forcing & Eddies, 1985.

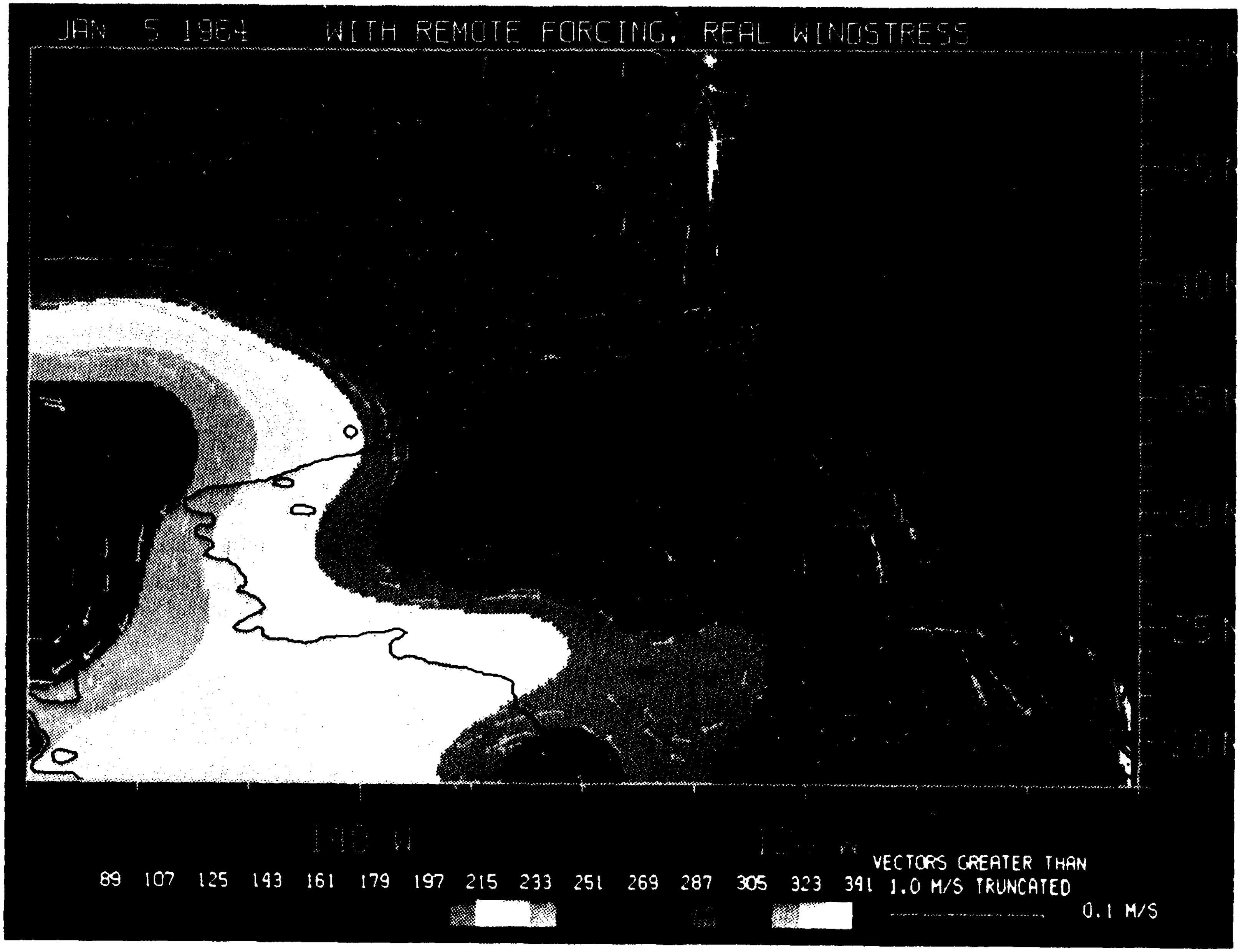


Figure 7. Bumpy Bottom, Wind & Remote, 1964.

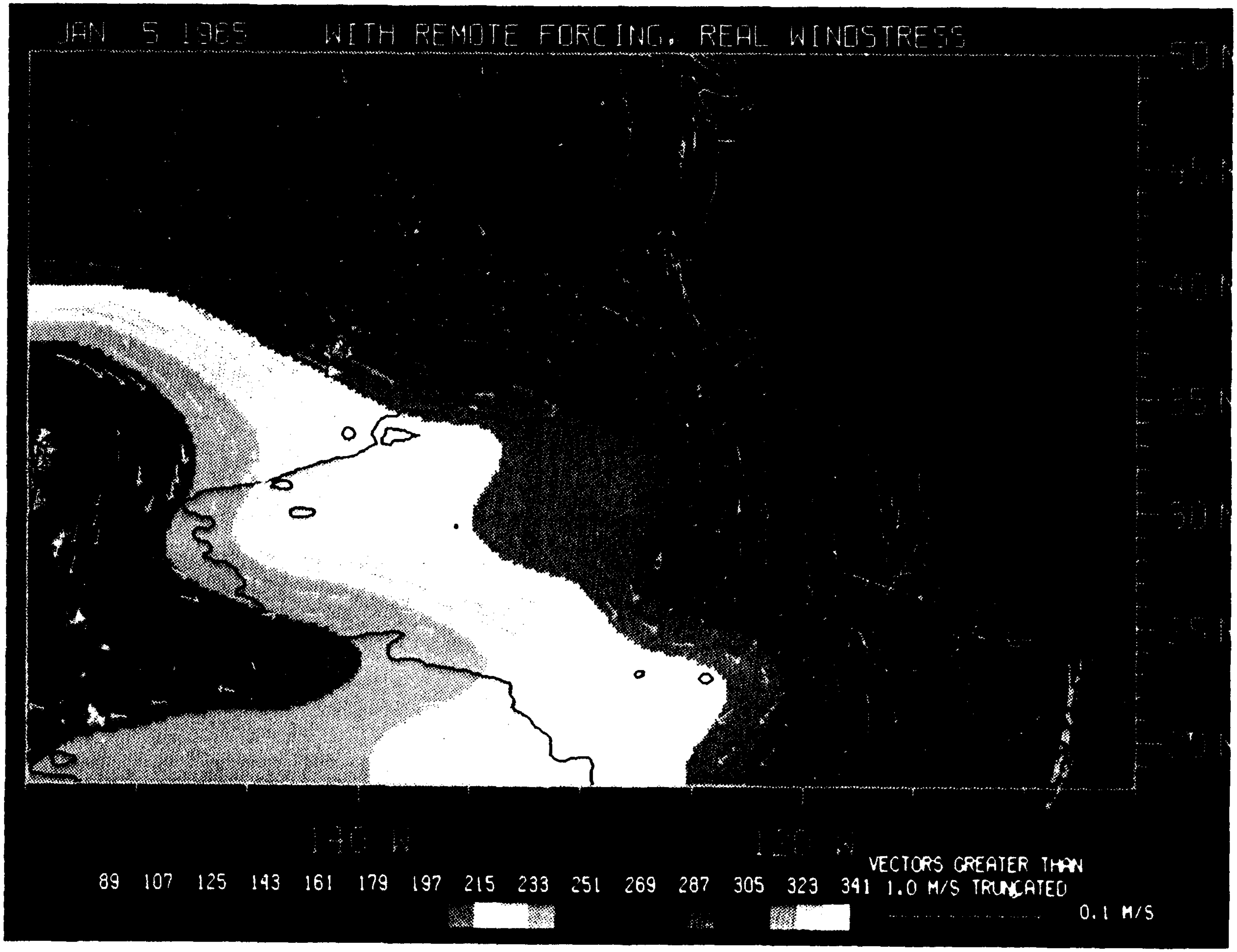


Figure 8. Bumpy Bottom, Wind & Remote, 1965.

Figure 9. Bumpy Bottom, 4 Year Kelvin, 4th Year.

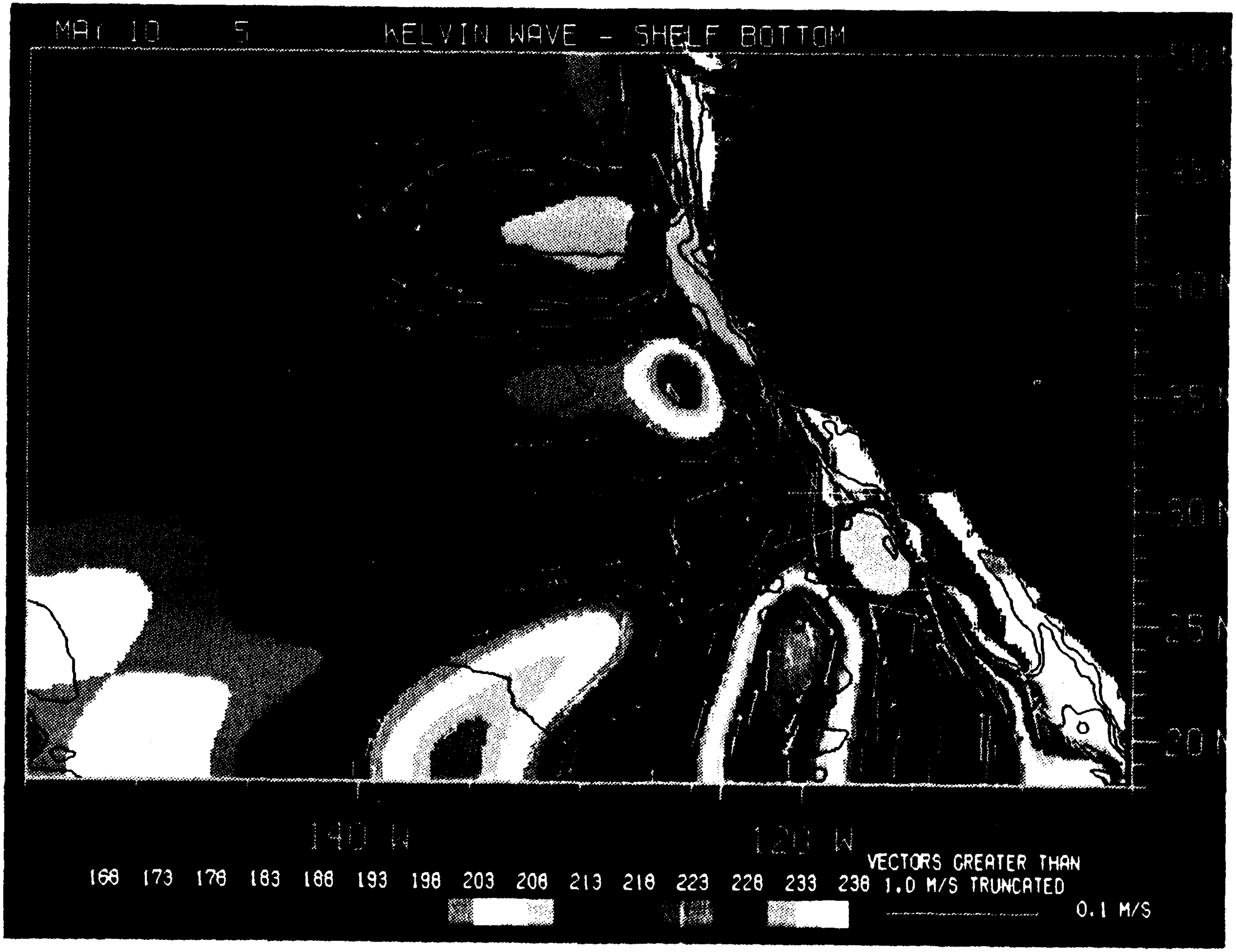


Figure 10. Bumpy Bottom, 1 Year Kelvin, 5th Year.

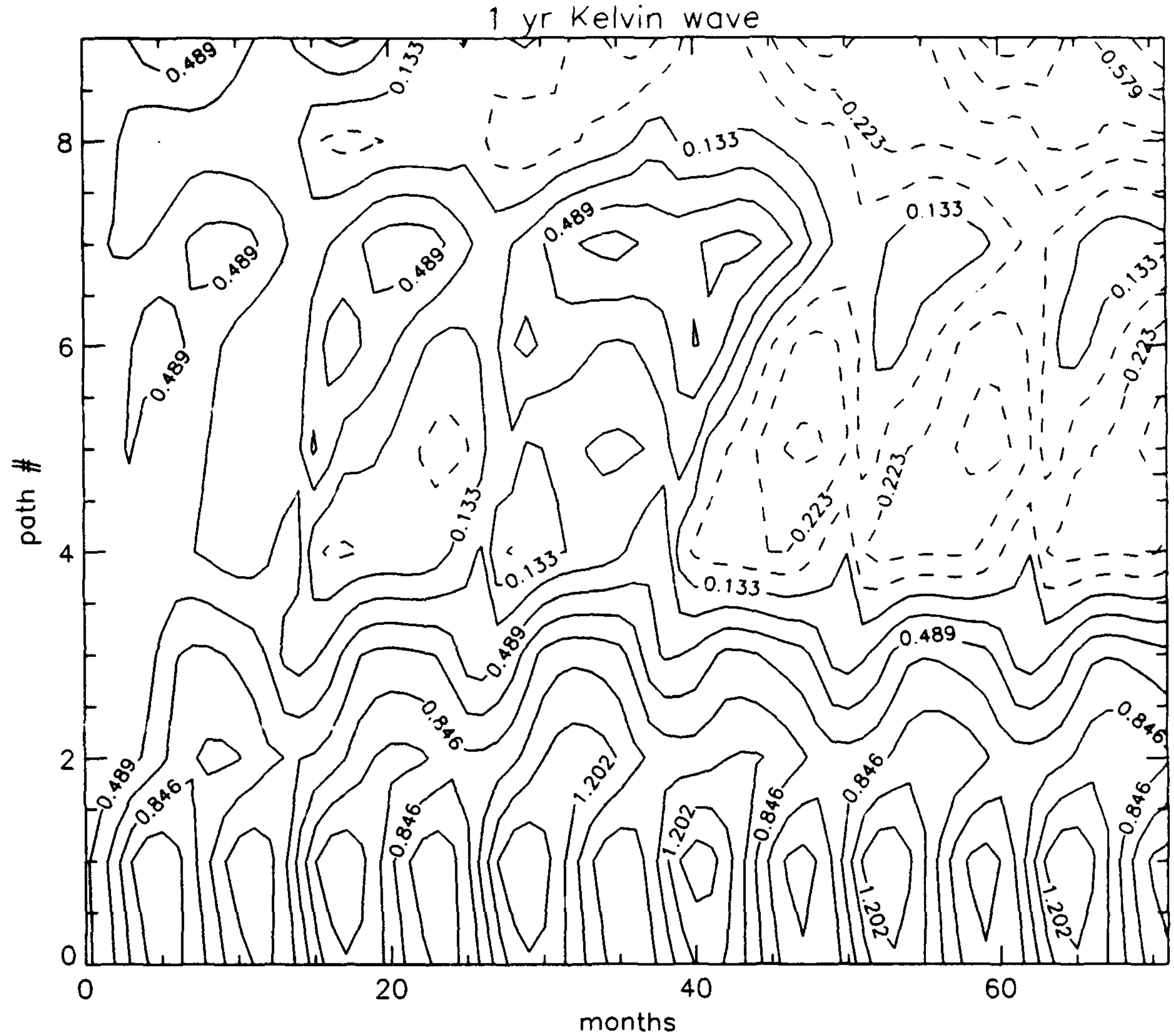


Fig 11 Travel time anomolies for model run (ii)

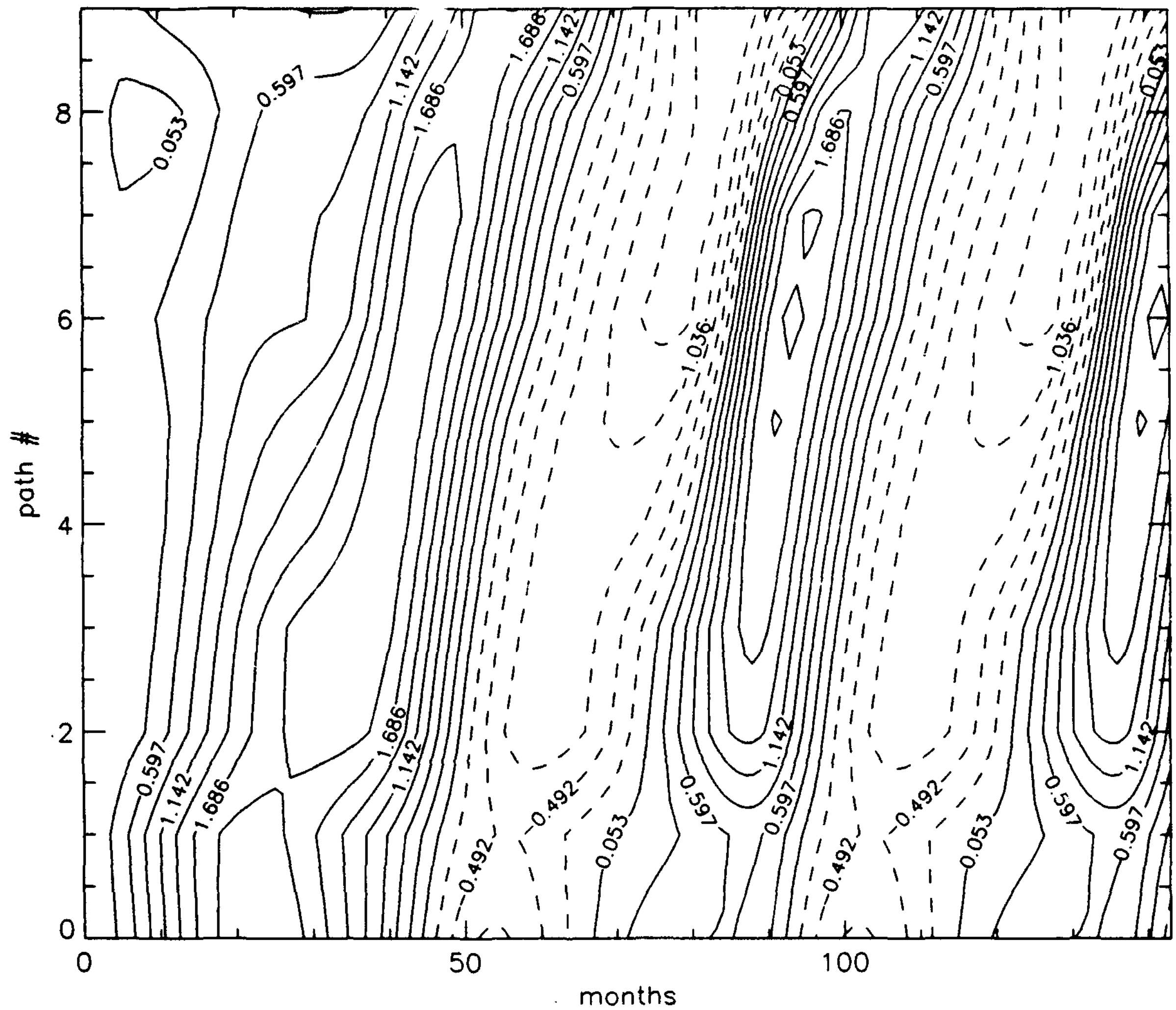


Fig 12 Travel time anomolies for model run (iii)

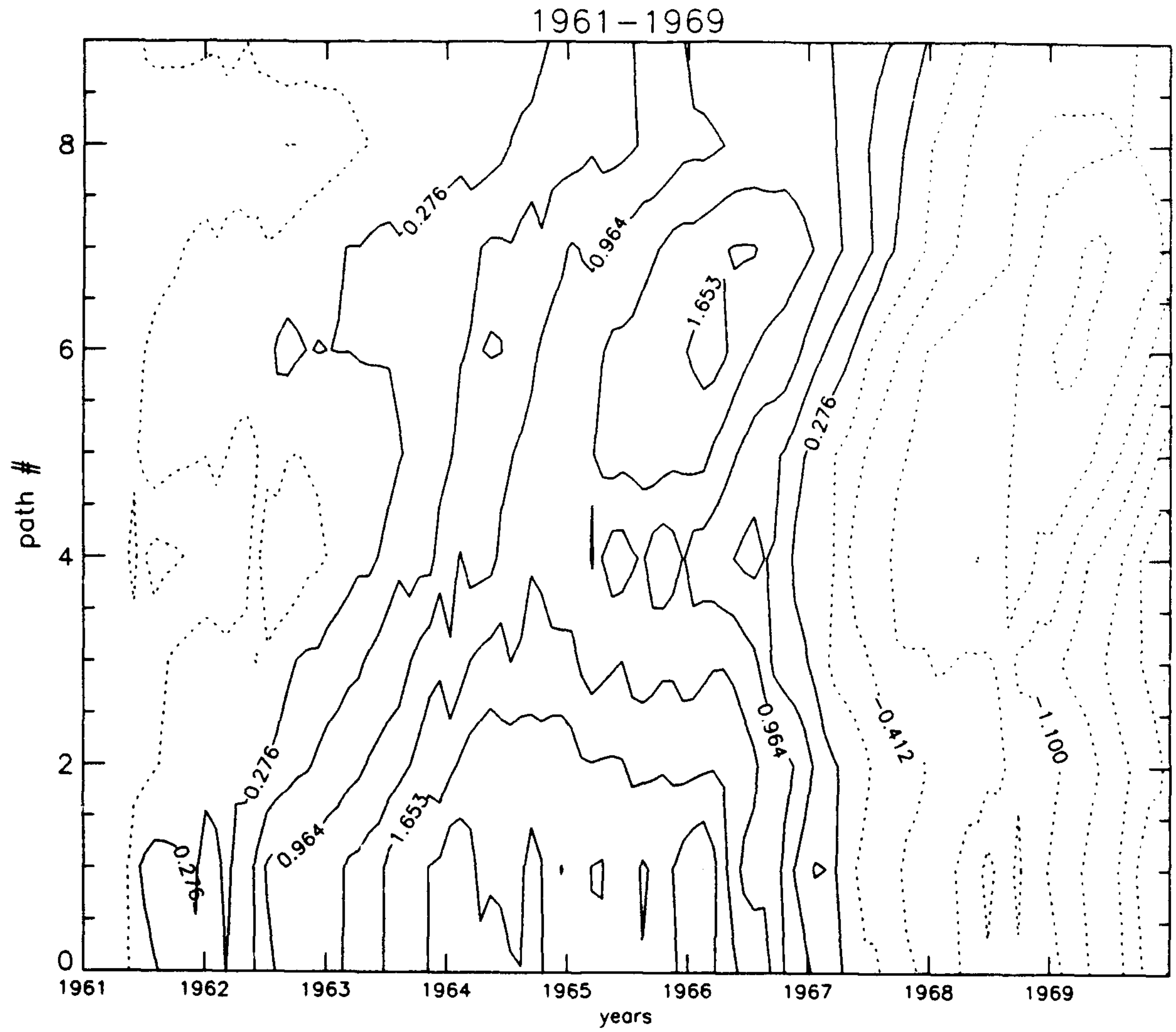


Fig 13 Travel time anomolies for model run (iv) 1961-1969

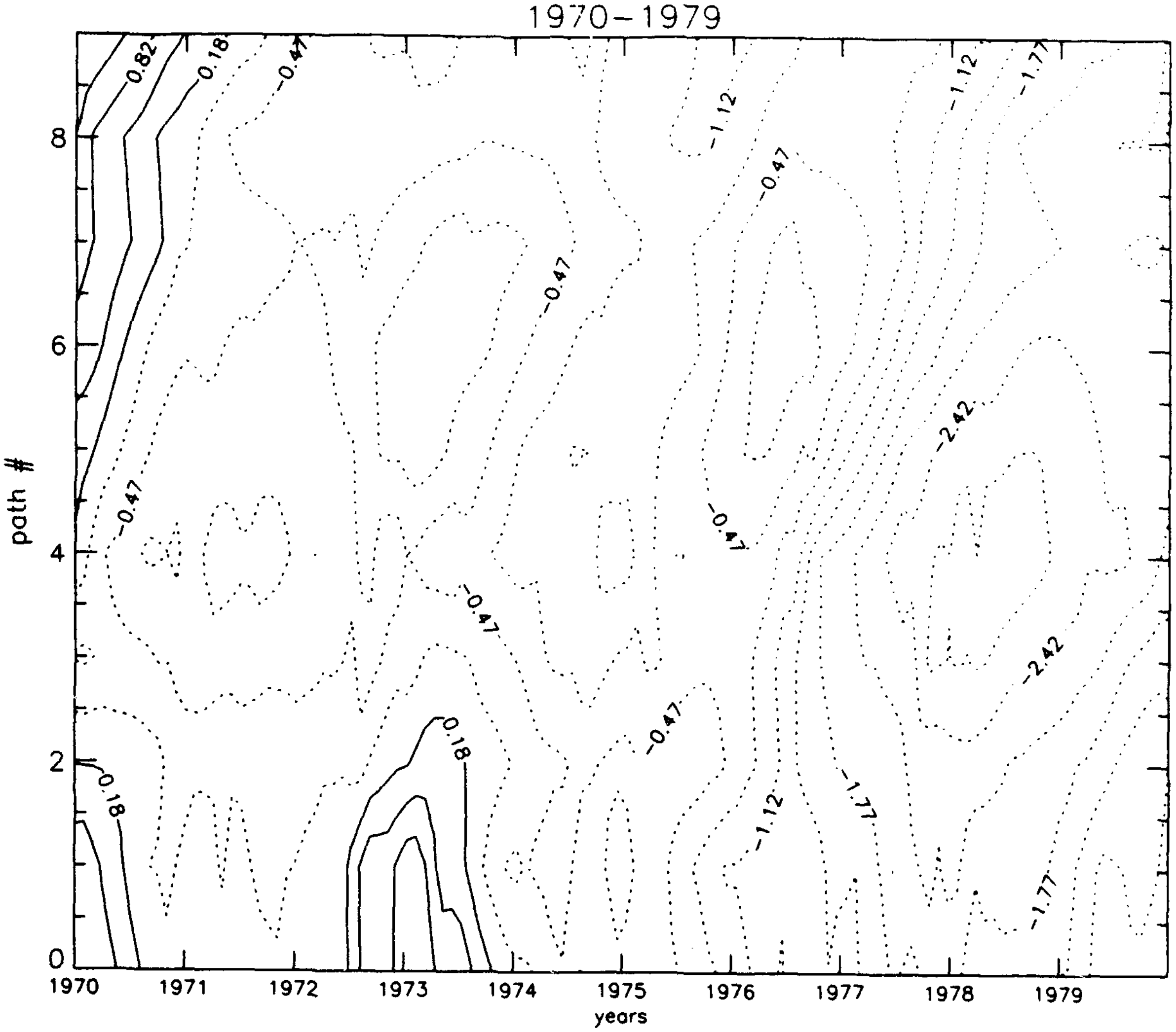


Fig 14 Travel time anomolies for model run (iv) 1970-1979

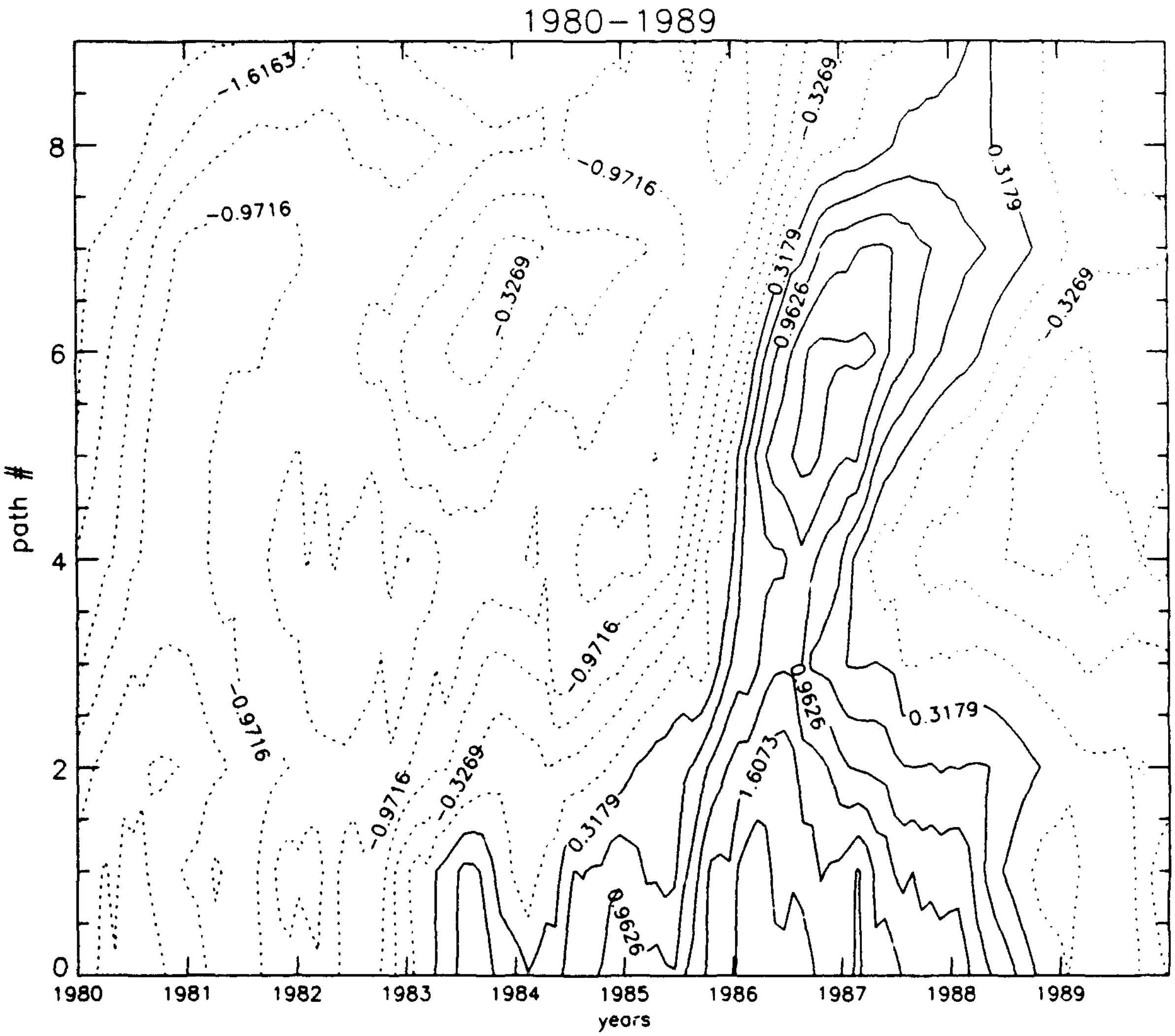


Fig 15 Travel time anomolies for model run (iv) 1980-1989

NUM	TASK B	Start Date	Finish Date
B.1	OBTAIN EQUATORIAL PAC WIND FIELDS FROM 80-91 AND DRIVE THE EQUATOR MODEL	4/14/93	5/31/93
B.2	EXTRACT THE COASTAL KELVIN SIGNAL FROM THE EQUATOR MODEL AND DRIVE THE MID LATITUDE MODEL	6/1/93	6/30/93
B.3	INTEGRATE THE MODEL SOLUTIONS BETWEEN HAWAII AND WEST COAST RCVRS	6/1/93	6/30/93
B.4	COMPARE WITH OBSERVATIONS AND IDENTIFY VARIABILITY IN ACOUSTIC TRAVEL TIMES	7/1/93	9/1/93
B.5	DESIGN FUTURE EXPERIMENTS	9/15/93	4/1/94
B.6	ADD MODEL COMPLEXITY AND VERTICAL STRUCTURE TO IMPROVE ESTIMATES OF TRAVEL TIME	4/15/94	9/1/94
B.7	RUN NRL MODELS	9/15/94	4/1/95
B.8	USE REAL DATA TO ASSIMILATE INTO OCEAN MODELS OF THE NORTH PACIFIC	9/15/94	4/1/95
B.9	SUBMIT FINAL REPORT	4/15/95	6/30/95

1993: A M J J A S O N D — 1994: J F M A M J J A S O N D — 1995: J F M A M J J

TASK C
SSAR DEVELOPMENT

Two of the three candidate SSAR designs were built and instrumented with sensors to measure and record their motions and the forces on their components during sea tests. Figure C.1 shows the two designs labeled Snubber and Standard. A dynamic model was developed to investigate the response of the SSAR to wave forcing. Figure C.2 shows the Snubber response to a typical ocean wave spectra where tension is measured just below the surface buoy. Figure C.3 shows the motions induced in the bottom and intermediate points of the Snubber design relative to the motion at the surface buoy. The key difference between the Snubber and the Standard design is that the Snubber design isolates the acoustic array from most of the high frequency motions (and forces) while the Standard design responds fully to most ocean wave frequencies.

The prototype SSARs were tested off the WHOI dock on Saturday, August 21, 1993, to test their weights and balances, to check for ground loops in the electrical systems, and to provide an end to end water test prior to shipment to Bermuda for the at sea tests. Various minor problems were uncovered and repaired as a result of this test.

The SSAR prototype mechanical systems were shipped to Bermuda via sea freight on August 24, 1993 with electronics systems shipped by air freight the following week. A test deployment was conducted between 16 September and 21 September offshore Bermuda. A detailed cruise report is attached as Appendix A. SSAR instrumentation, sample rates, and related information concerning this deployment is shown in Table C.1. The test deployment lasted five days during which time the buoys drifted approximately 25 miles. Examples of the high frequency data collected are shown in Figures C.4 through C.9. The test deployment was quite successful. The data collected is extremely high quality - some of the best of its kind ever collected on buoy response to wave and currents. The only failure in the data collection system was the hydrophone on the Snubber which failed due to an electronic problem.

ARL-UT personnel were on site for the Bermuda test to collect differential GPS data to compare to GPS data telemetered via Argos and post-processed. This data was collected successfully and is being analyzed at ARL-UT.

As a result of the initial prototype testing, we have revised our test plans for the the SSAR prototypes. A second trip to Bermuda is scheduled for early November where the Standard design will be fully instrumented for a short term at sea test. It will then be reconfigured with a smaller instrumentation suite (consistent with the Argos system data telemetry bandwidth) and set adrift for a long term trial. We will monitor this unit via its Argos link, but only retrieve it if it fails and is close to land or a ship of opportunity.

The Snubber design will be modified to reduce the length of the hose to 30 m and incorporate the electrical conductors in the hose wall. This will make the system more robust and should not have a major impact on system frequency response since the hose spring constant will be reduced to make it almost as soft as the present 73 m hose. Testing of a short hose segment of this design has begun at Tension Member Technology. These tests will determine whether the conductors can be safely protected in the hose wall and whether the hose is capable of withstanding the bending and loading anticipated over several years in the ocean. A test consisting of 500,000 cycles to full rated tension/bend is planned.

Following successful completion of these tests, we will have a number of these hoses built to our specification. The new Snubber design will then be tested in March 1994 in the Pacific. This test will incorporate both acoustic testing with full SSAR instrumentation and mechanical testing. A detailed test plan will be developed during the coming quarter.

Figure C.1 SSAR Standard and Snubber drifting buoy systems.

Figure C.2 Dynamic response of Snubber design to ocean waves.

Figure C.3 Dynamic response of surface buoy, subsurface buoy and acoustic array to ocean waves.

Figure C.4 Tension data from the Snubber buoy taken on September 18. In (A) the tension time series spanning about 2 1/2 minutes is shown. The data has been low-pass filtered at 2 Hz. Virtually all the energy in the signal is below 1 Hz, with the main spectral component at about 0.15 Hz.

Figure C.5 Raw X (horizontal) acceleration data from the Snubber surface buoy. Analog input filters are at 5 Hz. Peak accelerations are about one-half G.

Figure C.6 Raw Y (horizontal) acceleration data from the Snubber surface buoy. Analog input filters are at 5 Hz. Peak accelerations are about one-half G.

Figure C.7 Raw vertical acceleration from the Snubber surface buoy. Spectral content is very similar in shape to the tension data.

Figure C.8 Raw X (horizontal) acceleration from Snubber near the bottom of the cable. Analog input filters are at 70 Hz. Peak accelerations are about 1/30 of 1 G and correspond to strumming in the cable and small changes in tilt. Most of the energy lies between 1 and 3 Hz.

Figure C.9 Raw Y (horizontal) acceleration from Snubber near the bottom of the cable. Analog input filters are at 70 Hz. Peak accelerations are about 1/30 of 1 G and correspond to strumming in the cable and small changes in tilt. Most of the energy lies between 1 and 3 Hz.

Figure C.10 Raw vertical acceleration from the Snubber near the bottom of the cable. The strongest frequency component here is near the peak frequency observed in the tension data.

Figure C.11 Compass data from the electronics package at the bottom of the Snubber cable. This plot is an example of mild rotation experienced by the package. Most of this motion is very low frequency. The package rotates about 70 degrees in 30 seconds, then back the other way almost 90 degrees over another 30 seconds.

Figure C.12 Tension data from the Standard buoy taken on September 18. In (A) the tension time series spanning about 2 1/2 minutes is shown. The main spectral component at about 0.3 Hz (3 seconds).

Figure C.13 Compass data from the electronics package at the bottom of the Standard cable. This plot is an example of mild rotation experienced by the package. Most of this motion is very low frequency. Note that twice as much data is shown in this plot than on the plot of Snubber heading in Figure C.11. The package appears to rotate about 100 degrees at a time, then pause a moment before rotating back the other way.

Table C.1 SSAR Bermuda testing September 1993, summary of data collected.

Appendix A: Cruise report for September 1993 SSAR prototype test cruise

SSAR Bermuda Testing September 1993

Summary of Data Collected

Experiment Start/Stop Summary

Snubber: First in-water data set on day 260, 0400 GMT. Last in-water data set on day 264, 2000 GMT. Interval between data sets: 4 hours. Data sets taken at 0, 4, 8, 12, 16, 20 Hours GMT each day. Note: Snubber bottom last data set at 1600 day 262.

Standard: First in-water data set on day 259, 2100 GMT. Last in-water data set on day 264, 2100 GMT. Interval between data sets: 3 hours. Data sets taken at 0, 3, 6, 9, 12, 15, 18, 21 Hours GMT each day.

Sensor List

Buoy/System	Sensor	Rate	Duration	Comments
Snubber Top	6-DOF	50 Hz	1200 seconds	
	Tension	50 Hz	1200 seconds	
	GPS	0.1 Hz	1200 seconds	
Snubber Near	Pressure	n/a	1 instantaneous value	
	Tilt	50 Hz	90 seconds (avg, max, min, std, no time series)	
Snubber Bot.	Lin. Acc.	300 Hz.	240 seconds	
	Hydrophone	300 Hz	240 seconds	Not operational
	Tilt	300 Hz	240 seconds	
	Compass	1 Hz	240 seconds	
	Pressure	8 Hz	240 seconds	
Standard Top	Tension	50 Hz	1200 seconds	
	GPS	0.1 Hz	1200 seconds	
	Tilt	50 Hz	1200 seconds	
Standard Bot.	Hydrophone	300 Hz	240 seconds	
	Tilt	300 Hz	240 seconds	
	Compass	1 Hz	240 seconds	
	Pressure	8 Hz	240 seconds	

Data Format

A/D Data: Tension, acceleration and tilt are all sampled by the A/D. Data sets are 2 bytes per sample, bipolar 12 bit data range.

Table C.1

Pressure: Pressure data is recorded as ASCII directly from the sensor with command sequences embedded in it. All pressure data will be converted to ASCII floating-point numeric values in decibars (meters).

Compass: Heading data is recorded as ASCII directly from the sensor with command sequences embedded in it. All heading data will be converted to ASCII floating-point numeric values in degrees.

Units and Conversion:

The following are nominal values for sensors sampled by the A/D converter. Precise or updated values will accompany a more detailed report.

General: conversion from counts to volts is 20V/4096 = 4.883e-3 V per count.

Tension: 4.88 lbs per count. Standard buoy offset (no-load reading) was 44 mV when suspended by the endcap, 58 mV when sitting on the bench. Snubber buoy offset (no-load) was -10 mV when measured at WHOI, standing straight up, resting on the flange. Additional offset values will be determined from data sets taken prior to deployment and will accompany a more detailed report.

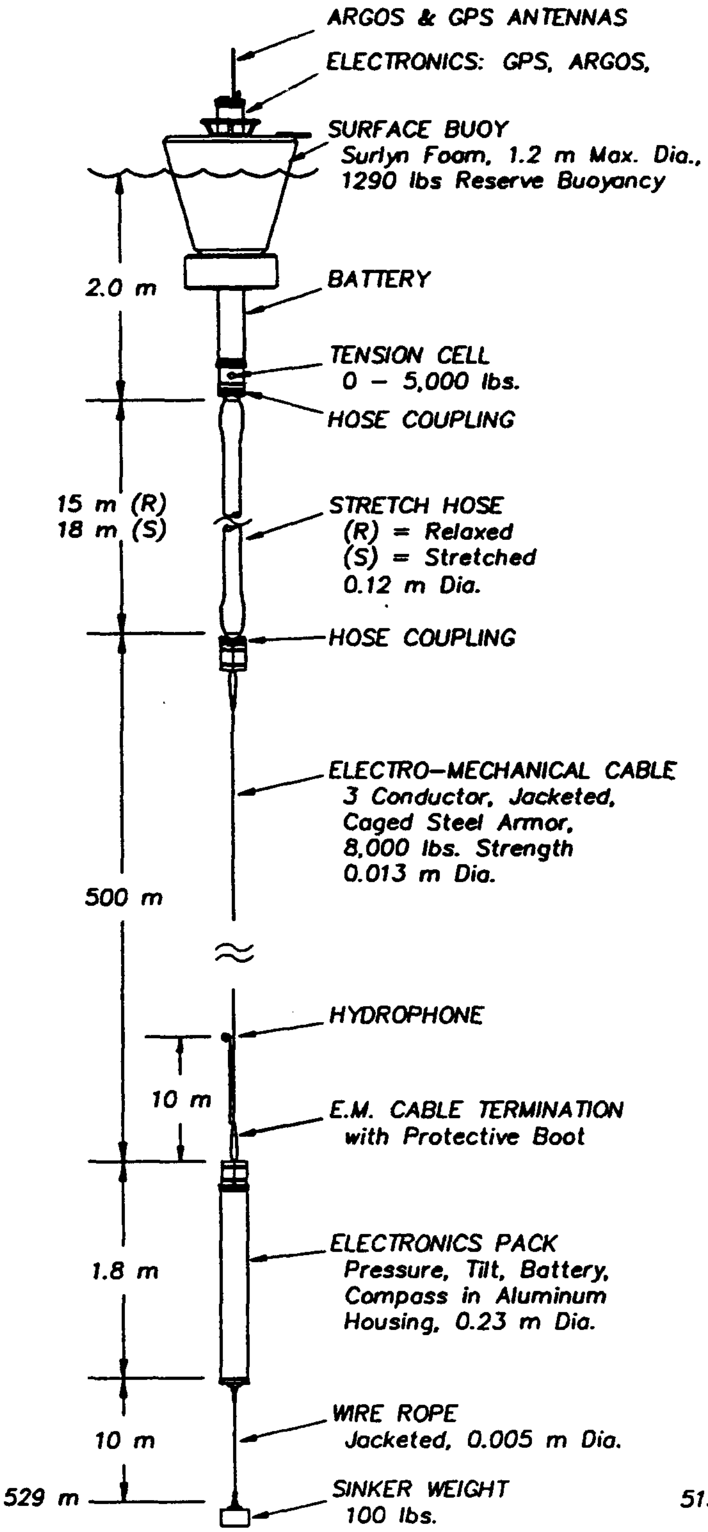
Linear Acc: 5 volts per G.

6-DOF: 3.75 volts per G for linear acc. 0.05 V/(deg/sec) for rate gyros.

Tilt: 0 degrees = 7.5 volts. 48 mV per degree of tilt. Calibration to be checked at the lab upon return of electronics from Bermuda.

Table C.1 (cont)

SSAR "Standard" Drifting Buoy System



SSAR "Snubber" Drifting Buoy System

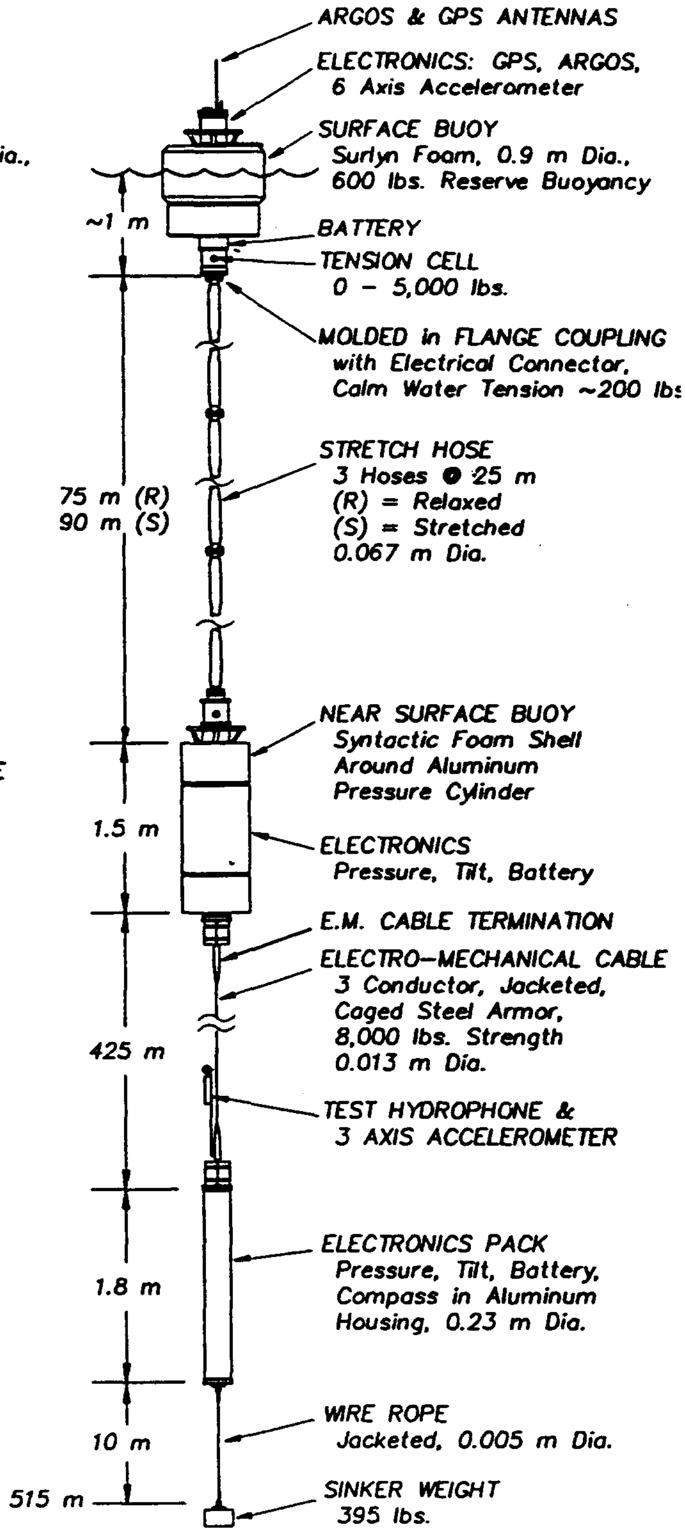


Figure C.1

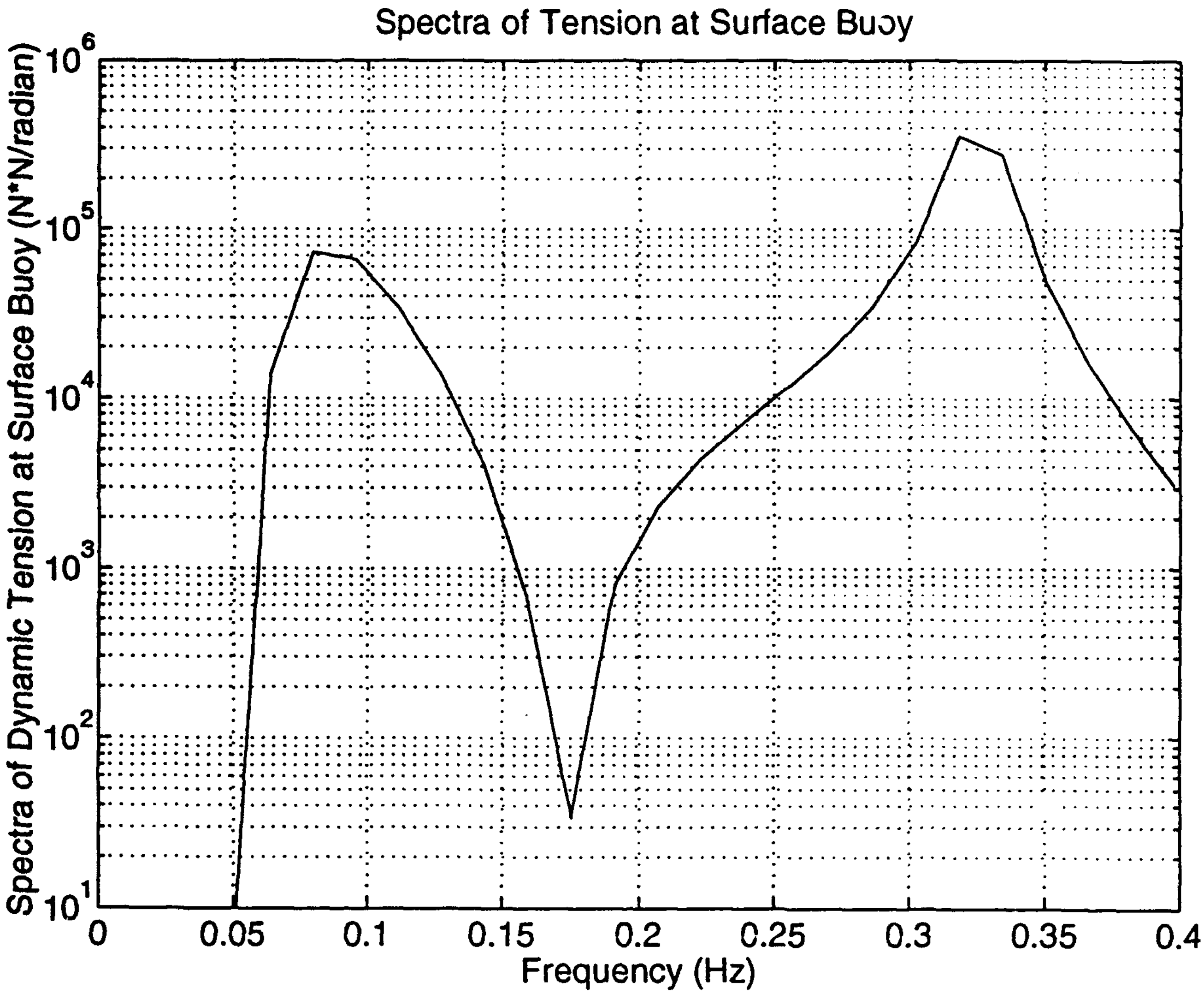

Spectra of Tension at Surface Buoy
Spectra of Dynamic Tension at Surface Buoy (N*N/radian)
10^6
10^5
10^4
10^3
10^2
10^1
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Frequency (Hz)

Figure C.2

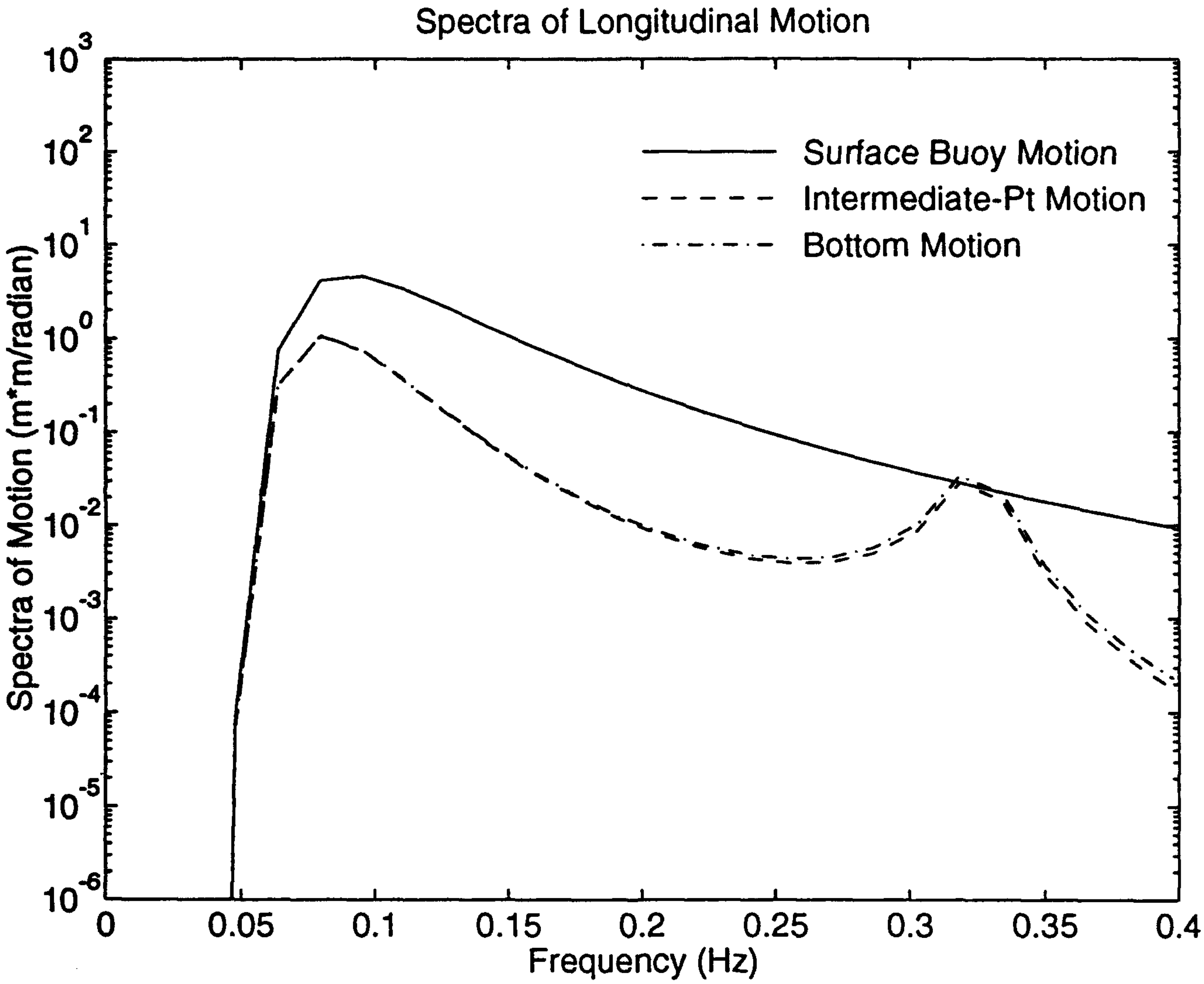

Spectra of Longitudinal Motion
Surface Buoy Motion
Intermediate-Pt Motion
Bottom Motion
Spectra of Motion (m*m/radian)
Frequency (Hz)
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

Figure C.3

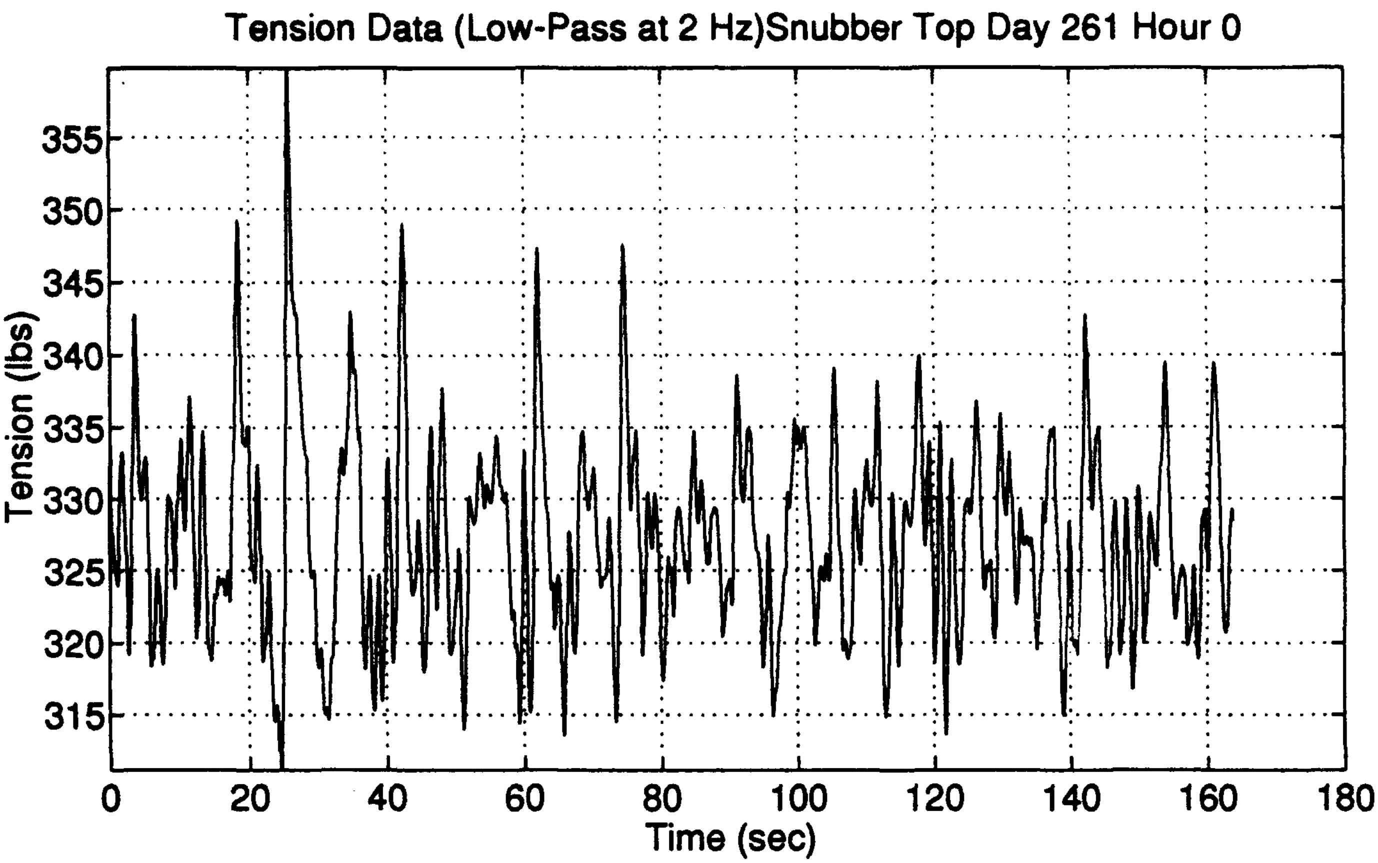


Figure C.4 (A)

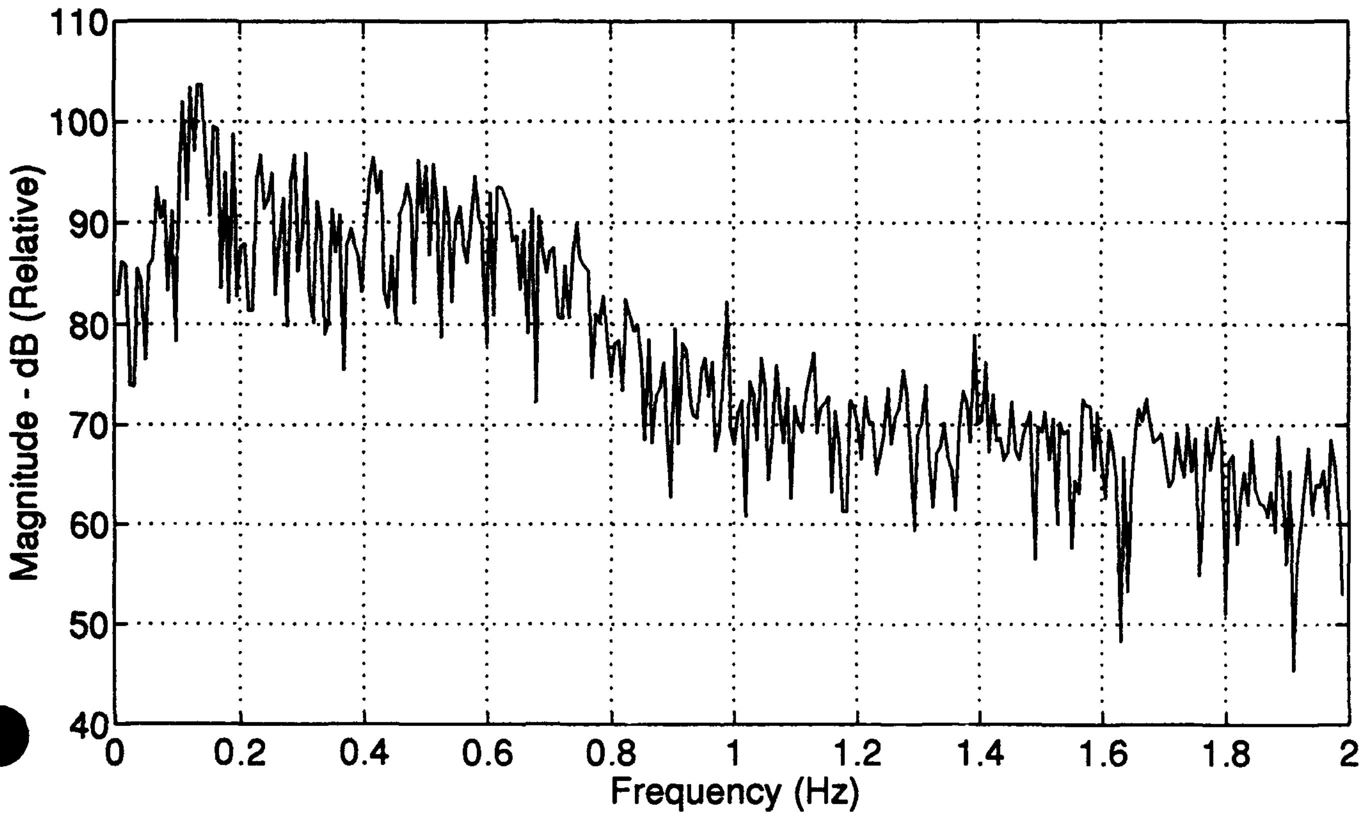
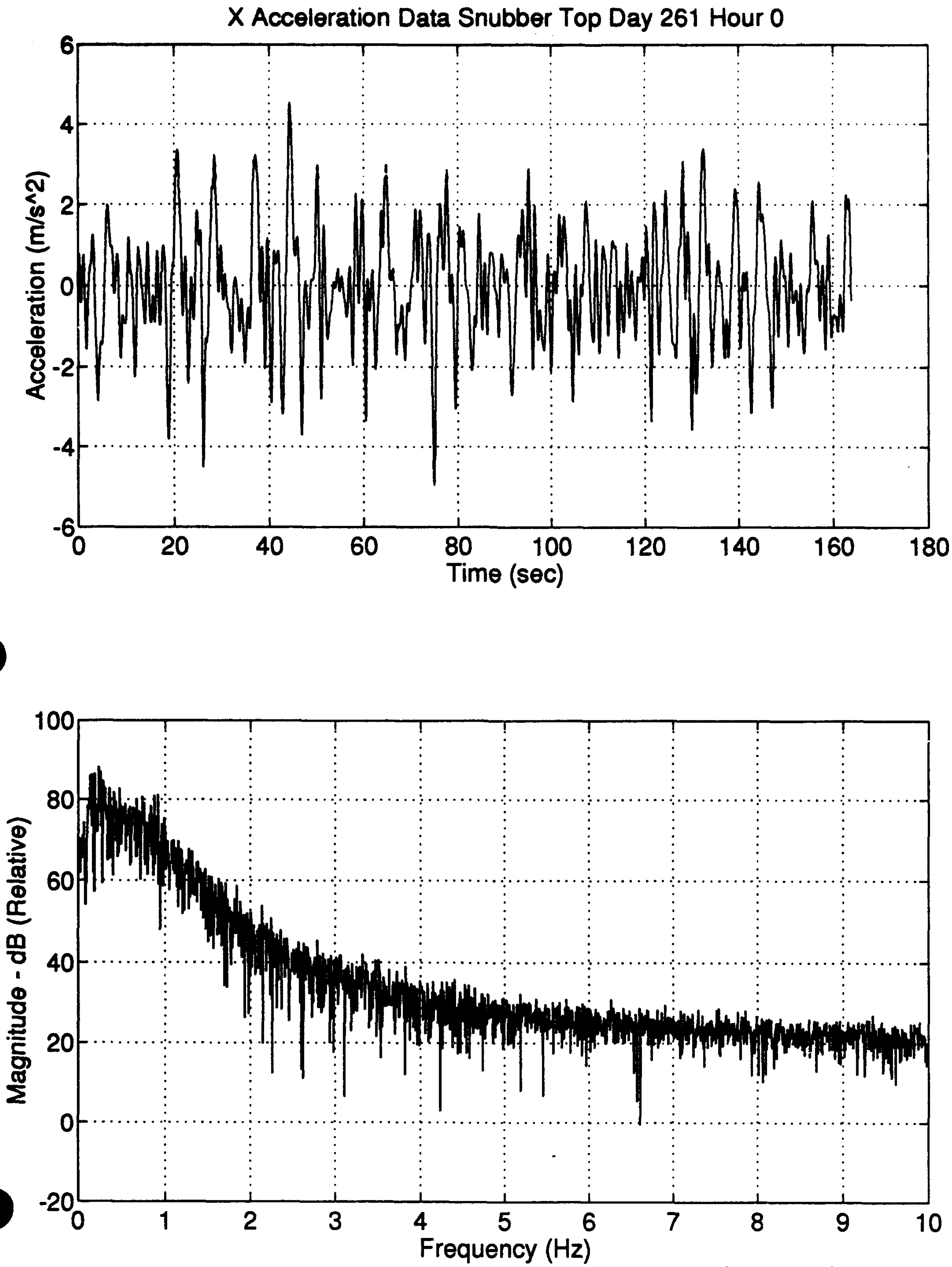


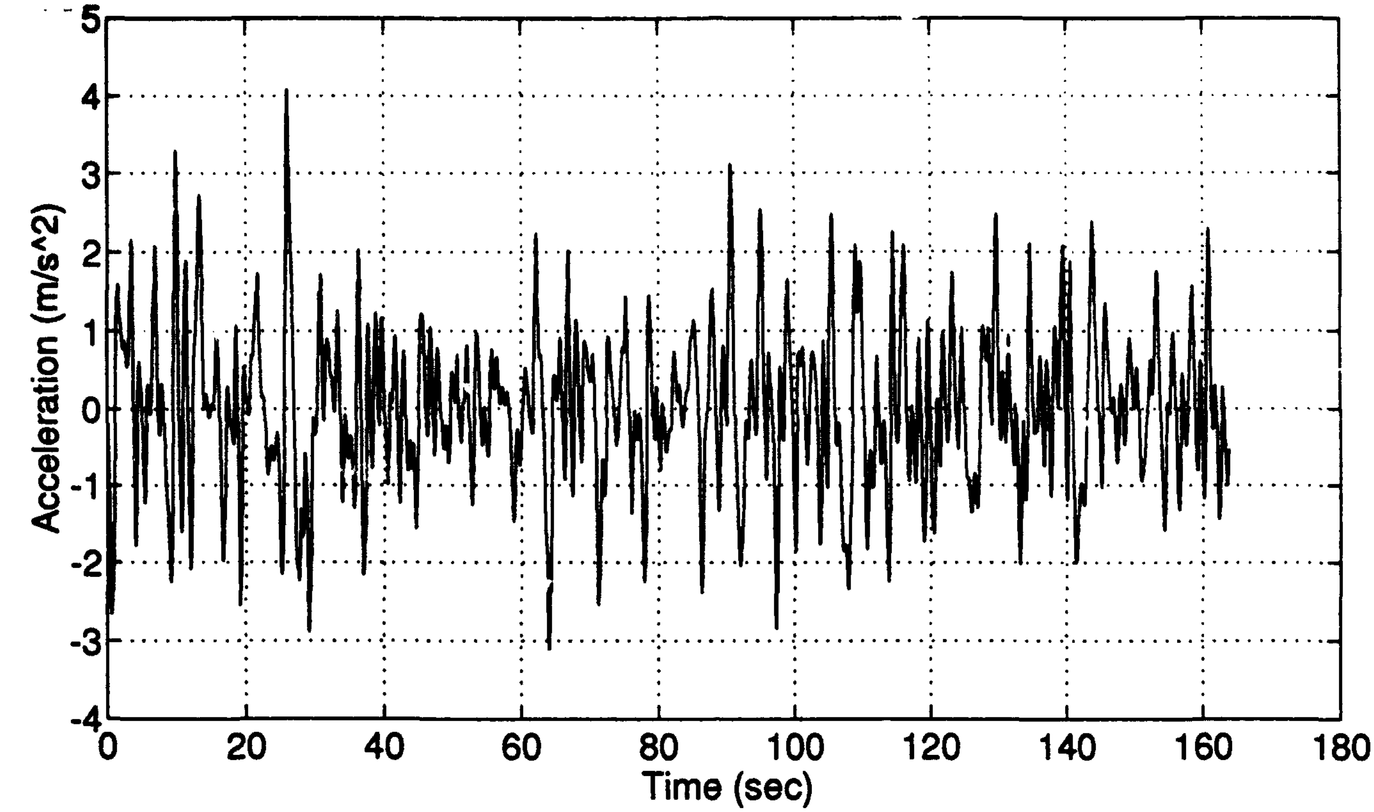
Figure C.4 (B)



X Acceleration Data Snubber Top Day 261 Hour 0
Acceleration (m/s^2)
6
4
2
0
-2
-4
-6
0
20
40
60
80
100
120
140
160
180
Time (sec)
Magnitude - dB (Relative)
100
80
60
40
20
0
-20
0
1
2
3
4
5
6
7
8
9
10
Frequency (Hz)

Figure C.5

Y Acceleration Data Snubber Top Day 261 Hour 0



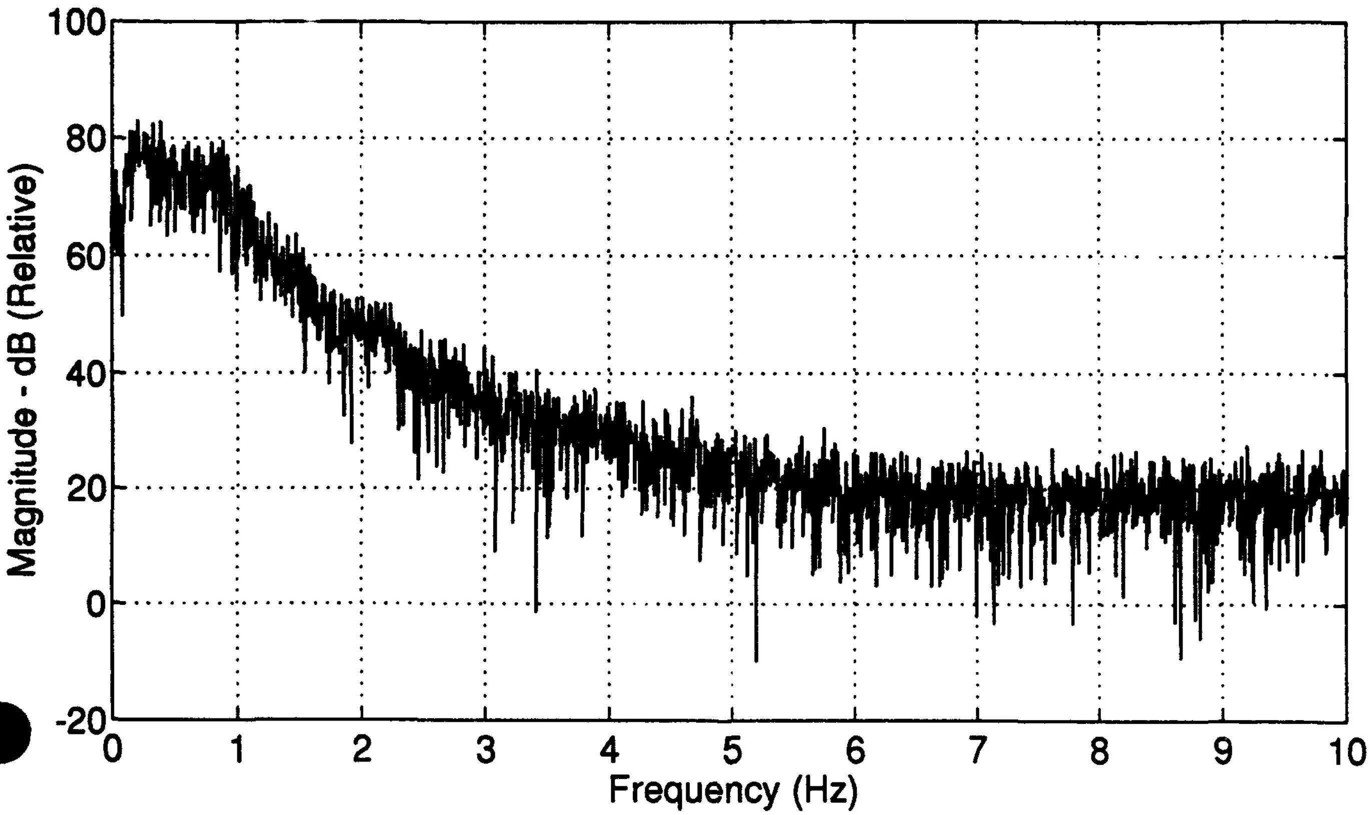
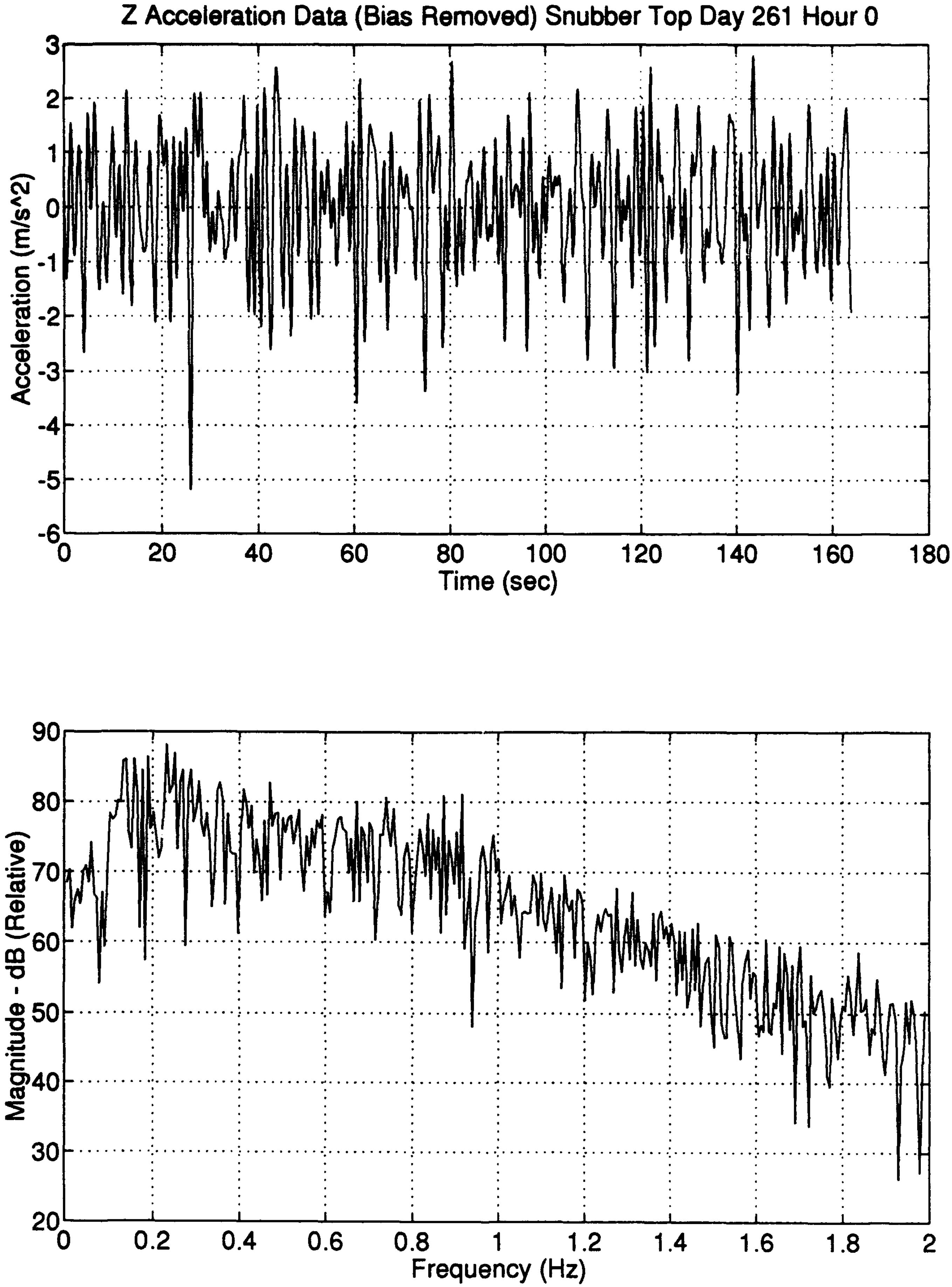
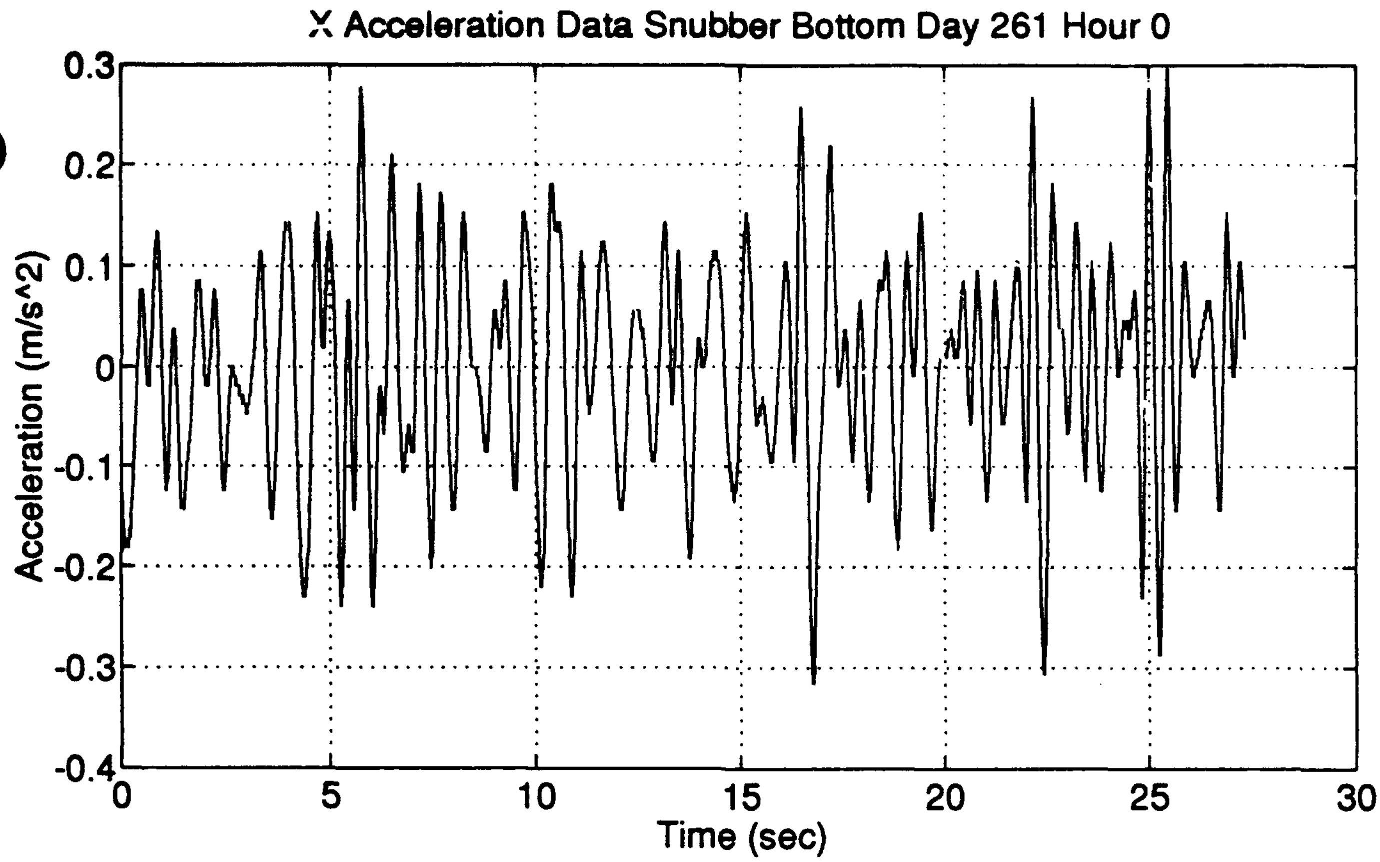


Figure C.6

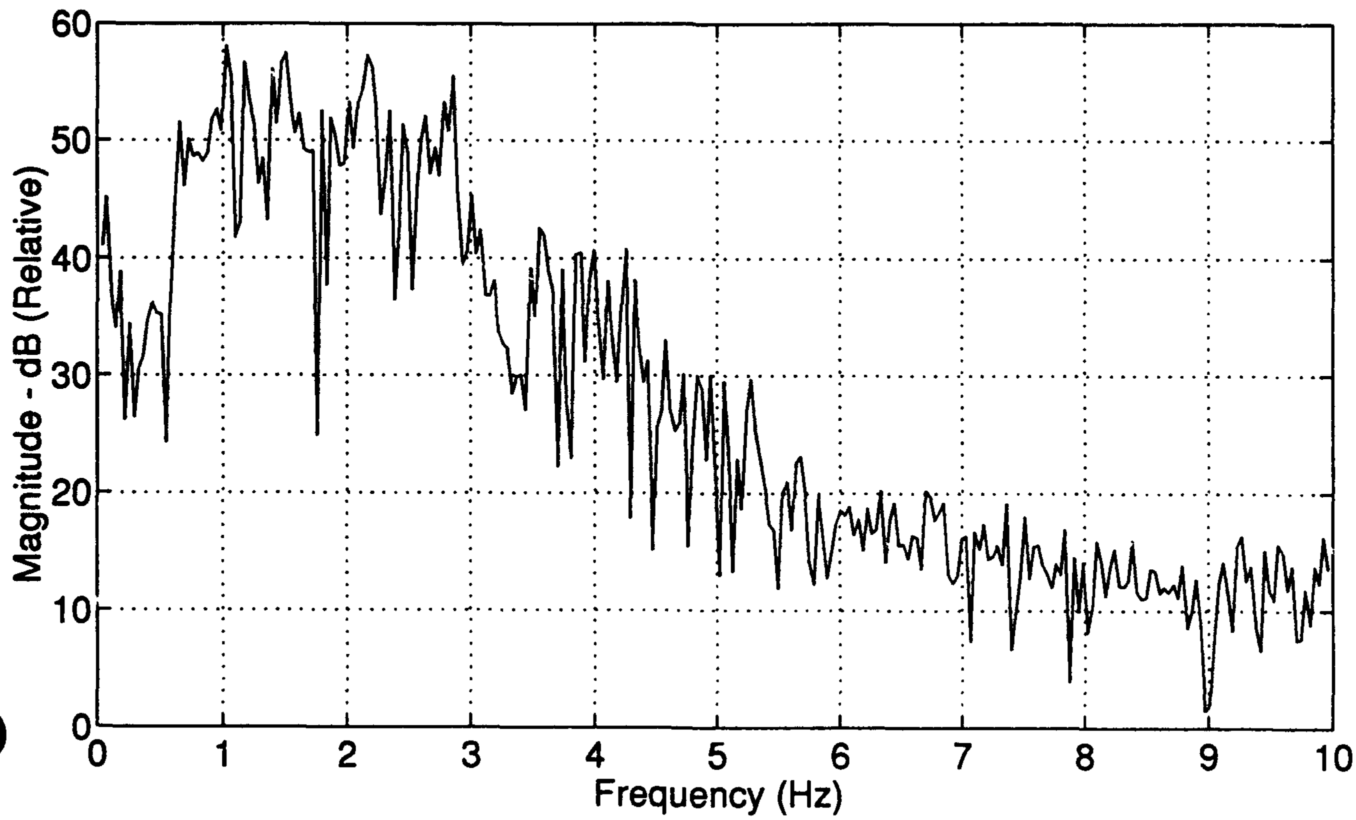


Z Acceleration Data (Bias Removed) Snubber Top Day 261 Hour 0
Acceleration (m/s^2)
Time (sec)
Magnitude - dB (Relative)
Frequency (Hz)

Figure C.7

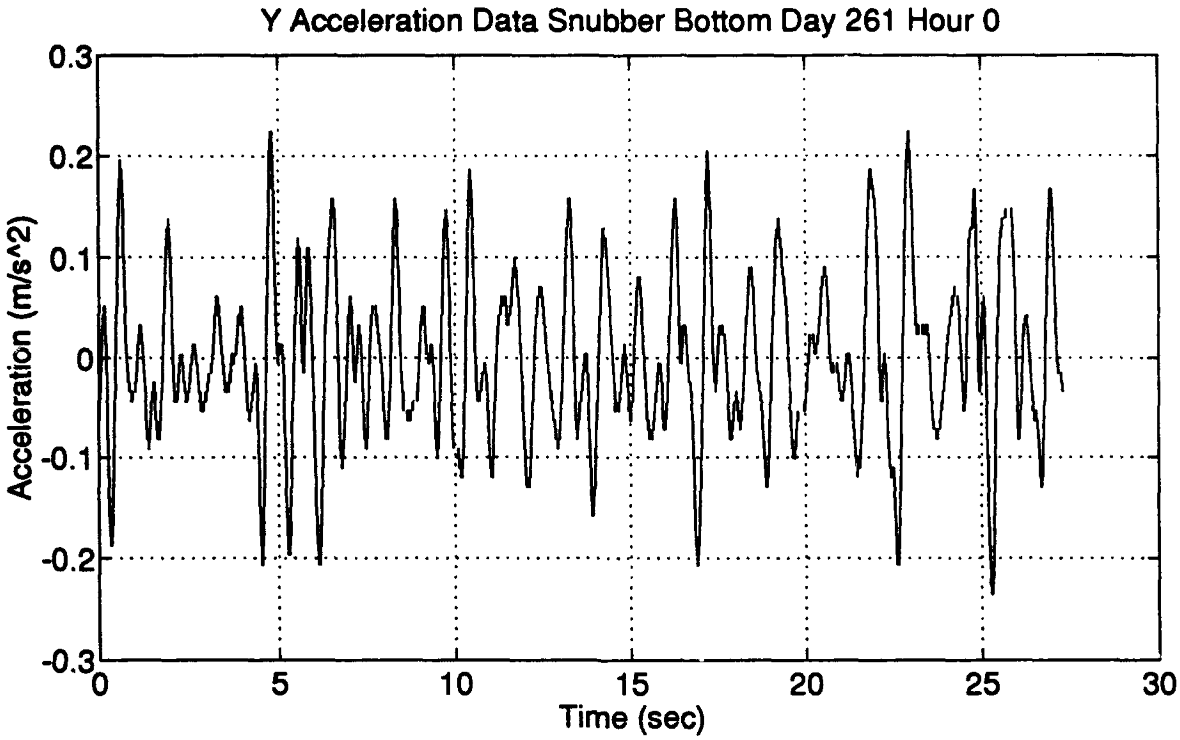


X Acceleration Data Snubber Bottom Day 261 Hour 0
Acceleration (m/s^2)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
5
10
15
20
25
30
Time (sec)

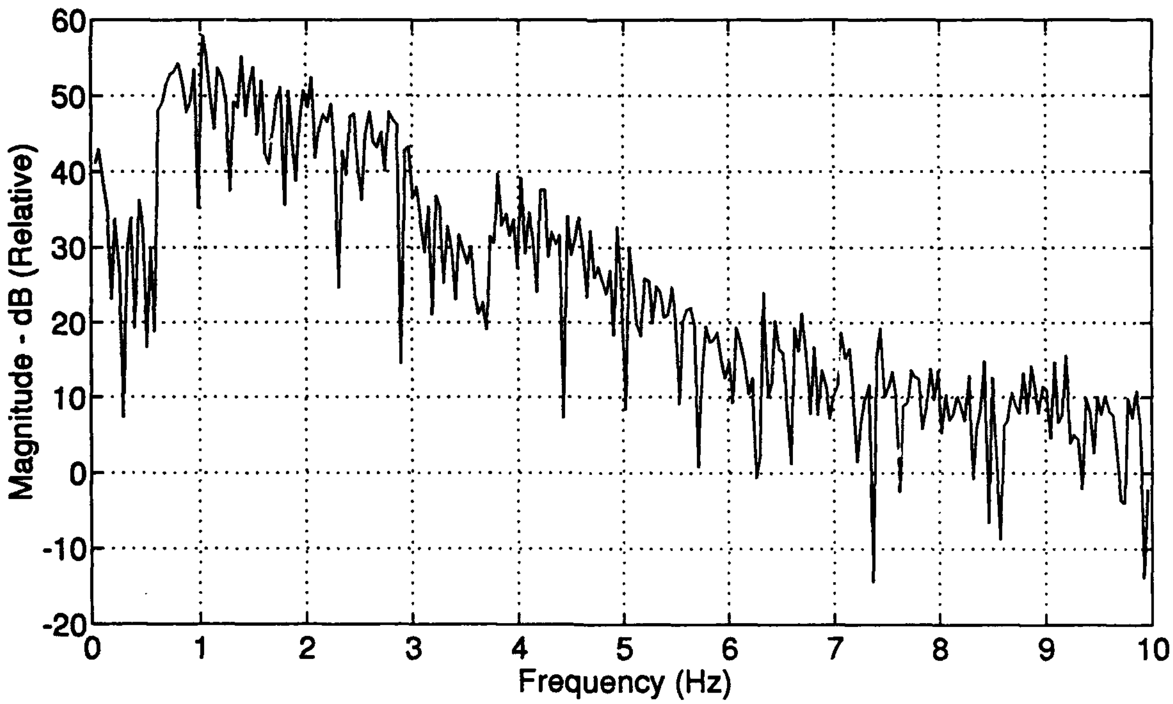


Magnitude - dB (Relative)
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
Frequency (Hz)

Figure C.8

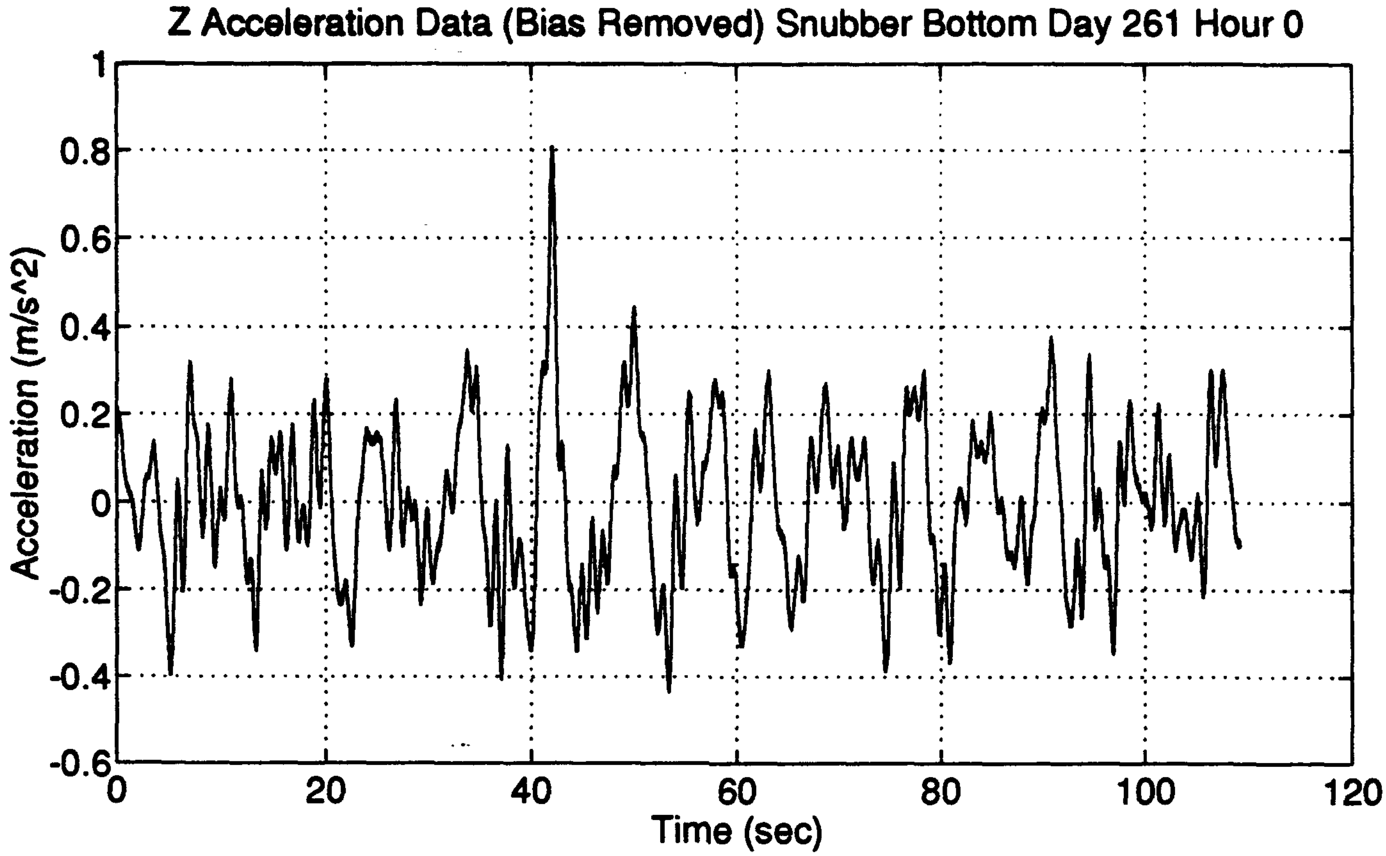


Y Acceleration Data Snubber Bottom Day 261 Hour 0
Acceleration (m/s^2)
Time (sec)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
5
10
15
20
25
30



Magnitude - dB (Relative)
Frequency (Hz)
60
50
40
30
20
10
0
-10
-20
0
1
2
3
4
5
6
7
8
9
10

Figure C.9


Z Acceleration Data (Bias Removed) Snubber Bottom Day 261 Hour 0
Acceleration (m/s^2)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
20
40
60
80
100
120
Time (sec)

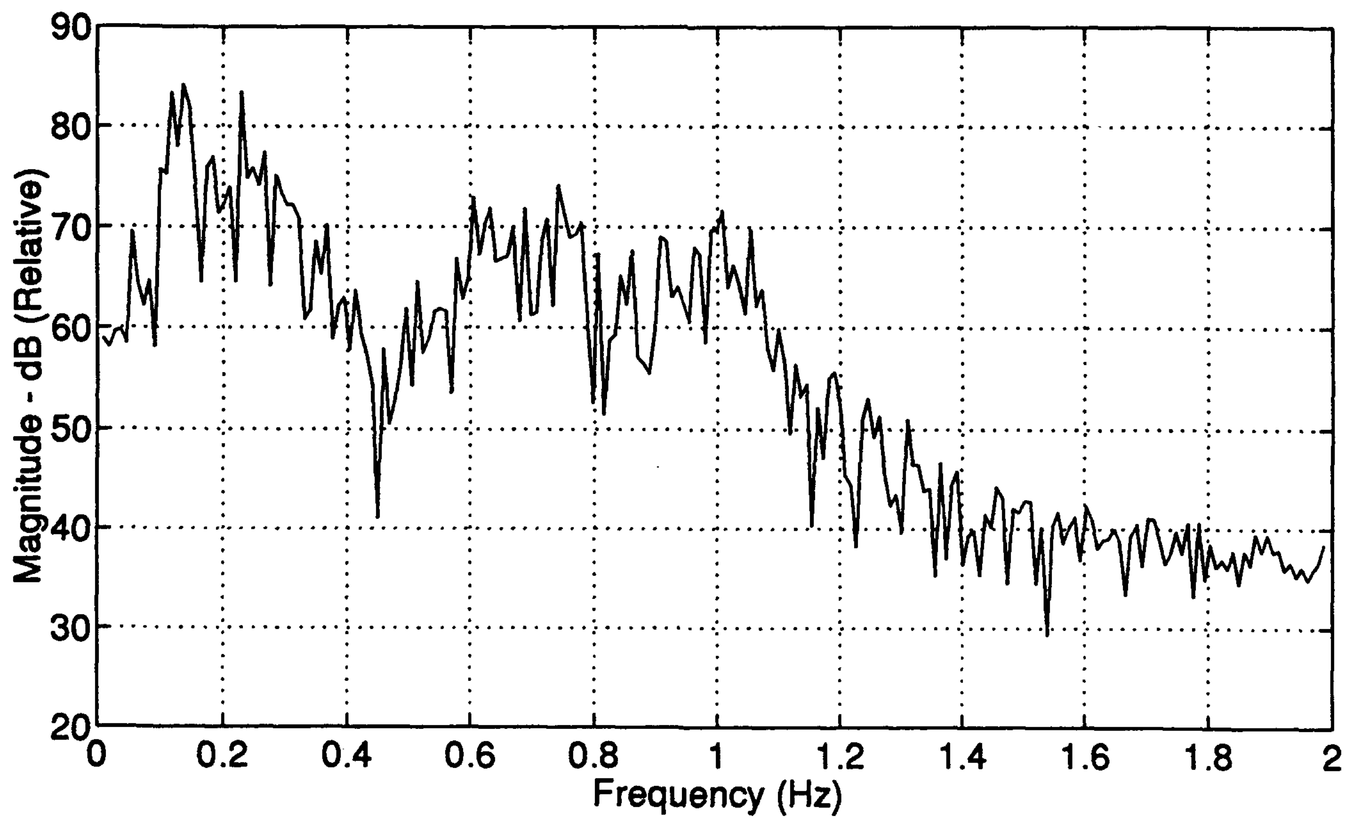

Magnitude - dB (Relative)
90
80
70
60
50
40
30
20
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Frequency (Hz)

Figure C.10

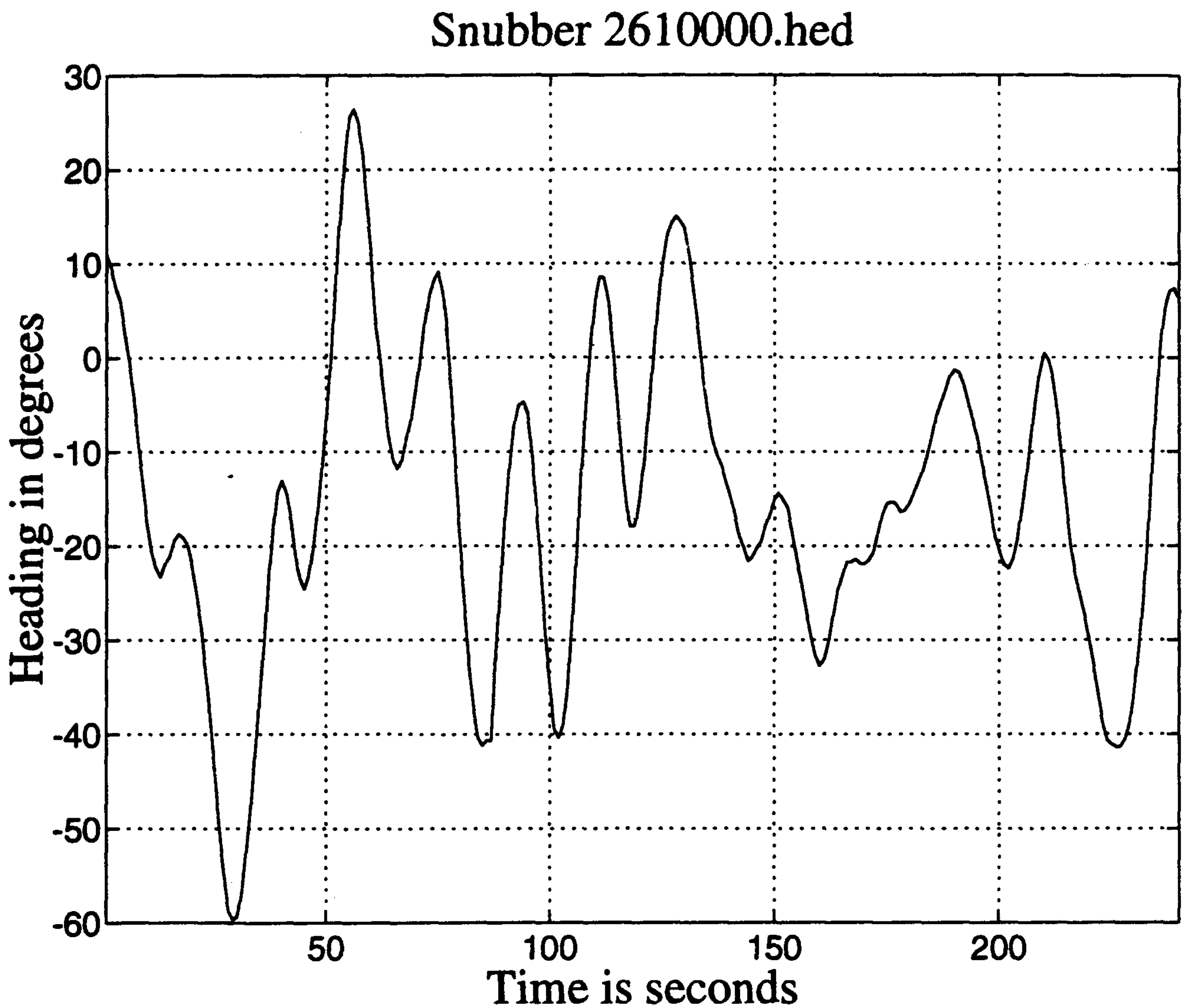
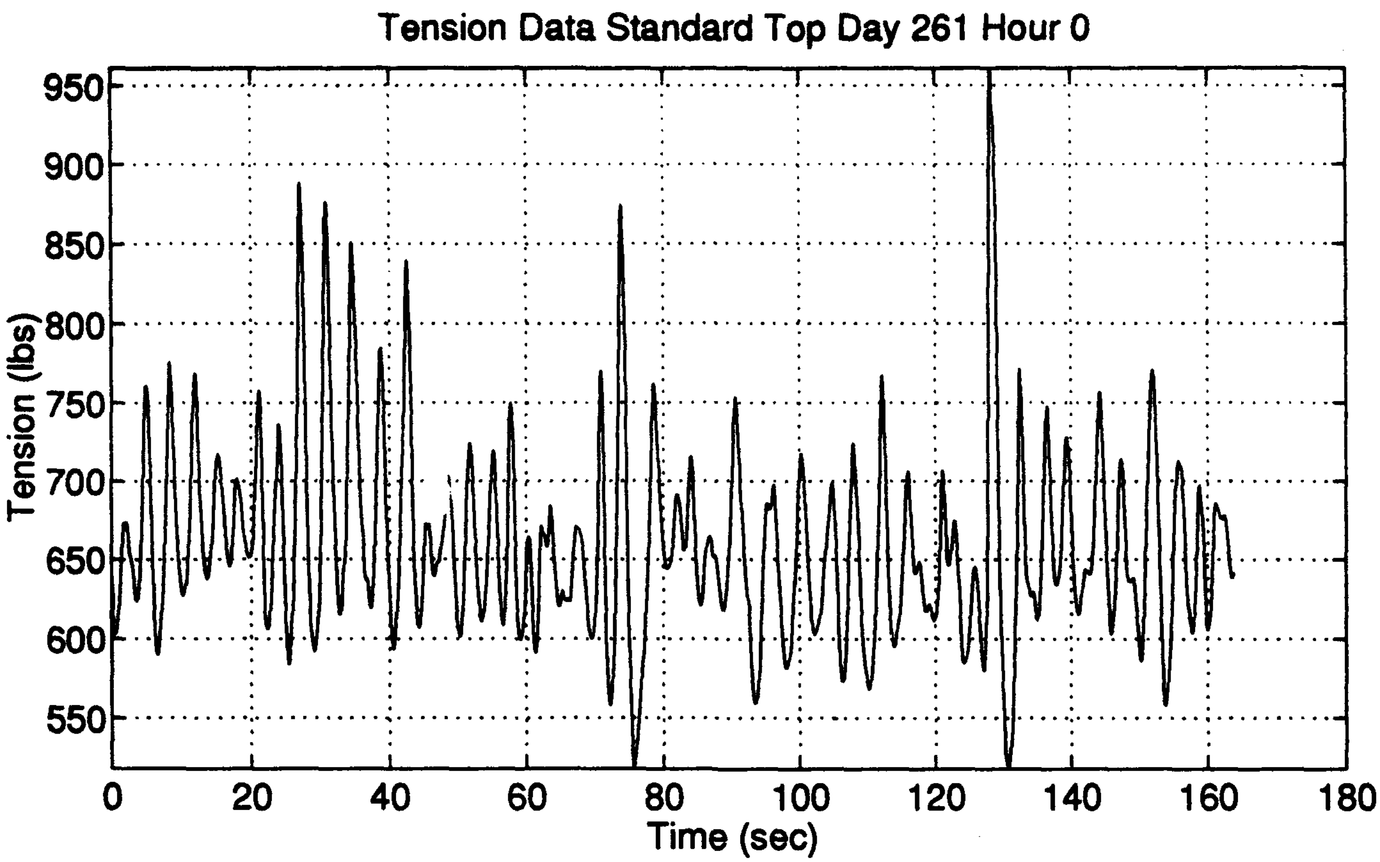

Snubber 2610000.hed
30
20
10
0
-10
-20
-30
-40
-50
-60
Heading in degrees
50
100
150
200
Time is seconds

Figure C.11


Tension Data Standard Top Day 261 Hour 0
Tension (lbs)
950
900
850
800
750
700
650
600
550
0
20
40
60
80
100
120
140
160
180
Time (sec)

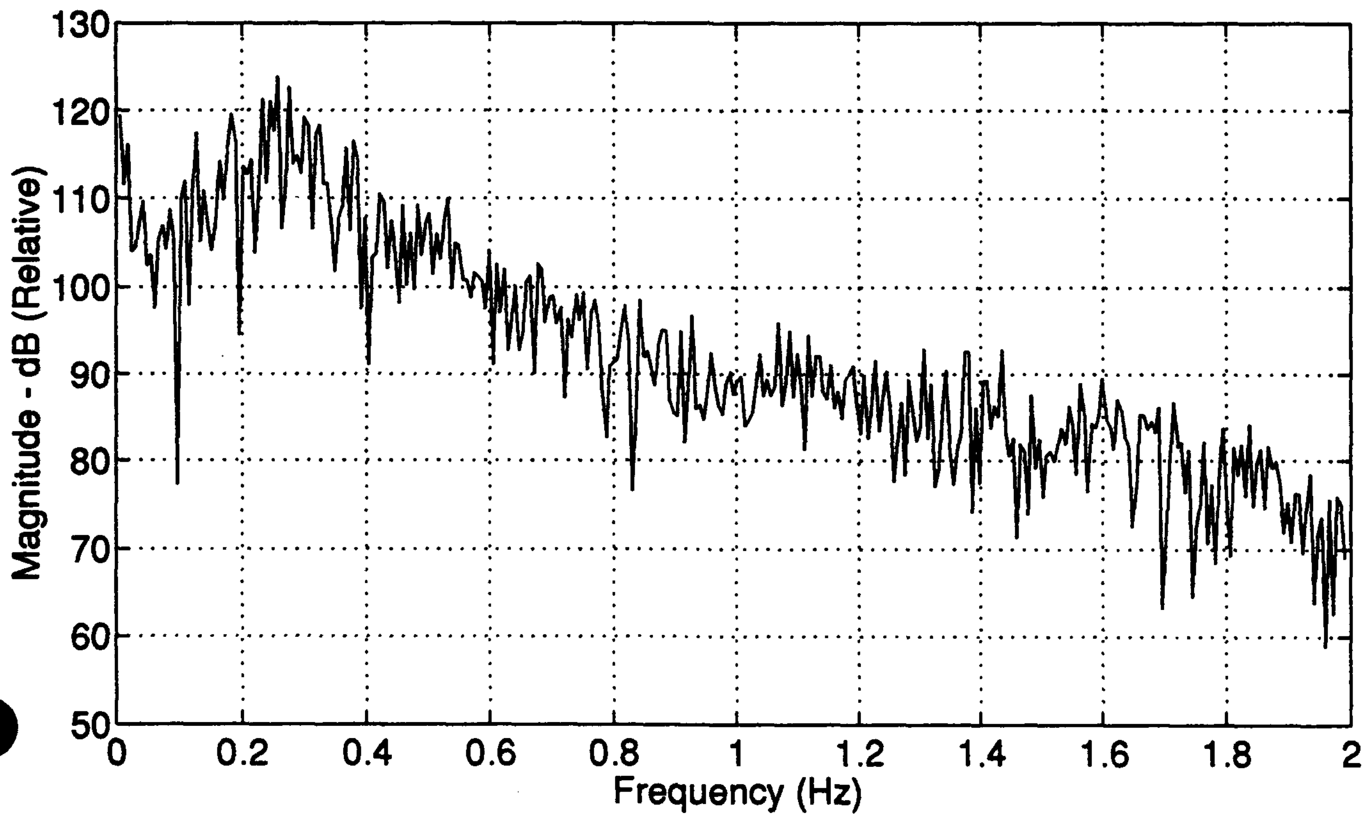

Magnitude - dB (Relative)
130
120
110
100
90
80
70
60
50
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Frequency (Hz)

Figure C.12

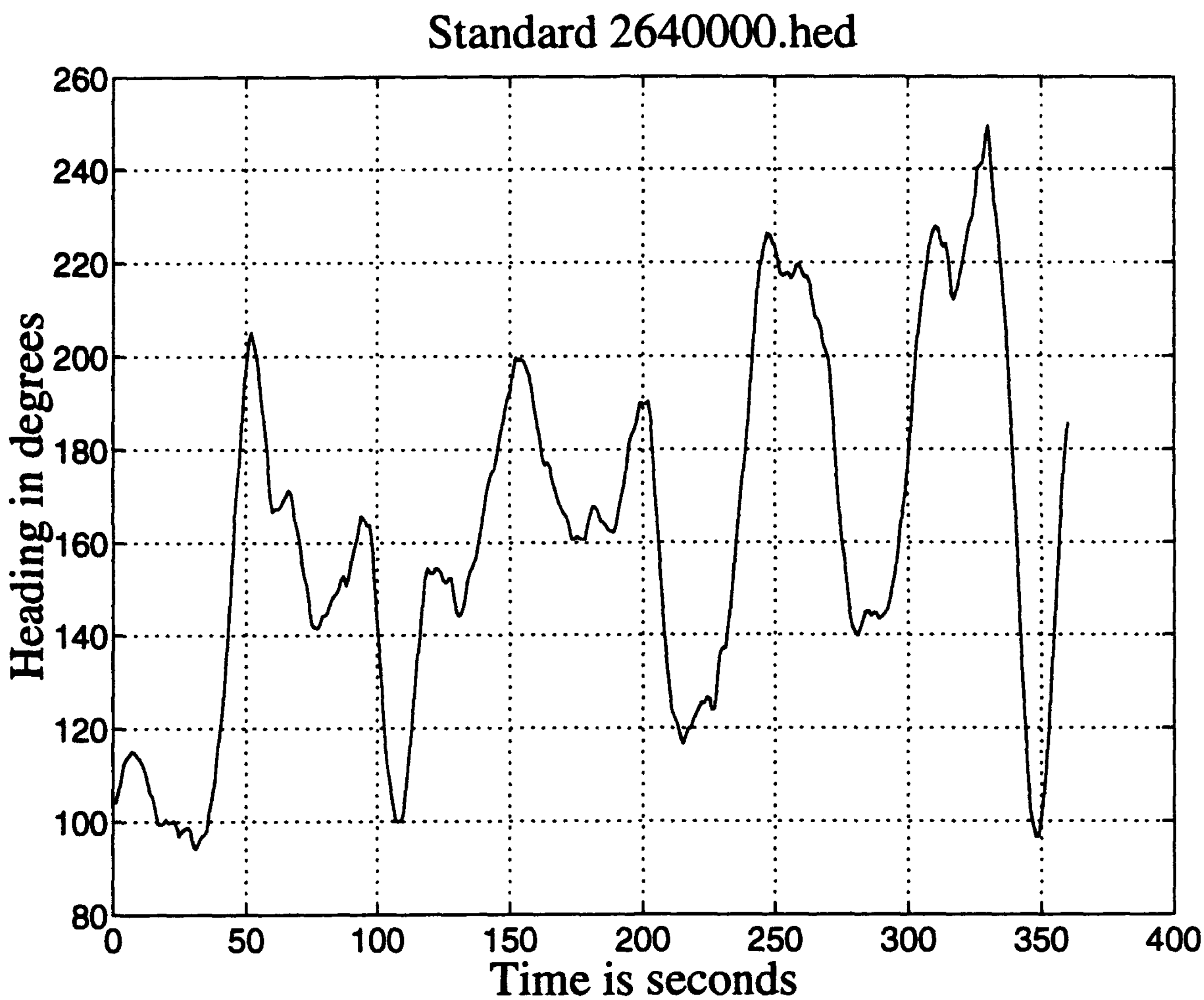

Standard 2640000.hed
Heading in degrees
260
240
220
200
180
160
140
120
100
80
0
50
100
150
200
250
300
350
400
Time is seconds

Figure C.13

REF: Epro ss0993.cr

CRUISE REPORT - SSAR PROTOTYPE SEA TEST

Purpose: A short open ocean test of the two prototype SSAR designs was planned to measure the forces on various elements of the systems and to monitor the motions resulting from wave and current forcing. To make these measurements, each SSAR was instrumented with sensors at the surface, at the bottom, and at the near surface (Snubber design only) pressure cases. High frequency data were recorded internally on hard disk and summary information was telemetered via Argos transmitter. Table 1 shows the details of the instrumentation deployed on each SSAR.

September 3-10, 1993

J. Kemp and A. Bocconcelli in Bermuda at the Biostation preparing SSAR mechanical components.

September 10, 1993

D. Frye, L. Freitag and E. Denton in Bermuda at the Biostation preparing the electronic systems for deployment. Set up electronics on the bench. Checked ship schedules. Frye gave newspaper interview.

September 11, 1993

Found problem with Argos transmitter (JZ) and Snubber disk drive power supply (for near surface). Sean McKee from ARL/UT arrived and began setting up the onshore GPS station. Installed Biostation reference at south end of Arco Lab. Wrote abstract for Brighton conference on the SSAR design/at sea test results.

Continued testing Argos PTTs. Finalized data buffer content on Argos messages.

September 12, 1993

Surveyed in the GPS site at the Arco Lab using USGS survey locations at the Shell depot across the road from the Biostation. Installed the electronics and batteries in the surface and bottom pressure cases for the Standard SSAR. Wired in all cables and set them up for an overnight test with a high speed sampling rate.

Continued bench tests of Snubber system.

September 13, 1993

Checked the overnight test of Standard. Two problems identified. Argos transmitter failed. This is same unit we had problems with before so we installed a spare unit. The acoustic noise measurement was too low so we increased the amplifier gain.

Checked tilt sensors, pressure sensors and tension sensors to make sure they were operational and were not contaminated by noise.

Monitored ALTOMOOR currents to estimate SSAR drift rate. Currents were 10-20 cm/s to the northeast at 200 m depth. ALTOMOOR is located in the general location where the SSARs will be deployed.

Began an overnight test on the Standard system - slow mode.
Began an overnight test on the Snubber system with all cables and hoses installed - fast mode.

September 14, 1993

Analyzed overnight test results.

Found problem with Snubber hydrophone data - noisy. Pulled electronics, substituted Standard unit. Found potential wiring problem and corrected. Lost some GPS data on Standard. Pulled unit and checked - appears okay. Problem seems to be in the communication link. Re-wrote code to allow for multiple attempts to transfer GPS data. This appeared to solve the problem.

Rewrote cruise plan - deployment data set for 16 September. Had spare receiver parts for hydrophone sent from Falmouth. Reinstalled all electronics for final overnight test.

September 15, 1993

Analyzed overnight test results.

All systems look good, except Snubber hydrophone - still noisy.

Set system for final operating mode. Checked ALTOMOOR current data. Loaded equipment on ship. Set up lab with test equipment, tracking system, Argos receiver. Tested RDF system.

September 16, 1993

	Checked Argos data - everything okay except Snubber hydrophone.
0900	Departed dock - transit to deployment site about 35 nautical miles SE of Bermuda.
	BATS crew did an optical cast at noon.
	Weather - winds 10-15 knots, seas 2-3 feet, fair.
	All systems functioning normally. Unplugged monitoring cables from surface units.
	Argos DF working normally with units on deck.
1340	Began Standard SSAR deployment
1506	Completed Standard SSAR deployment. Location 31°59.68' N, 64°21.39'W.
1700	Test range and accuracy of RDF by steaming away from the buoy. Data PTT with disk antenna could only be heard for 0.5 miles. APIRB PTT on Webb antenna heard up to 2.5 miles - good direction for about 1.2 miles.
1730	Prepare for Snubber deployment.
1930	Start Snubber deployment
2126	Finish Snubber deployment. Seas 2-4', winds 10-15 knots. Checked visibility of SSAR flashing lights Can see for about 3 miles in this sea state. BATS crew took over ship - steamed to BATS site.

September 17, 1993

1500	Working at BATS site. Got buoy position update from Capt. Black via HF radio for 1151Z. Weather 15-20 knots, seas 3-6'
1700	Finished BATS work. Headed back to Bermuda via SSARs. Located both buoys. Both appear to be doing fine.
2300	Arrived back at Biostation.

September 18-20, 1993

Monitored Argos transmissions from both buoys. Tracked their drift track.

Problems:
1. Gradual increase in tension below the Snubber surface buoy. We guessed that the Snubber hose was leaking oil and filling with water.
2. Telemetry from bottom pressure case on Snubber ceased on 9/19.
3. Some GPS data missing on Snubber.

September 21, 1993

Decided to retrieve buoys. Snubber seems to be stabilized, but we think its prudent to retrieve it now. Got updated Argos positions. Arranged to get future positions via HF if needed.

1300 Sailed for estimated SSAR position.

1415 Picked up ALTOMOOR anchor at commercial dock. Headed for Snubber SSAR.

1800 Visual sighting of Snubber very close to estimated position.

1830 Began Snubber retrieval.

Surface buoy looked good, 8-10" of freeboard. Both GPS and disk Argos antennas had salt deposits. Hose looked good at top, but bottom 1/3 was flat. Also hose appeared to be stretched to limit of stop rope. Bottom 10 or 15 feet were twisted 3 or 4 times. Bottom pressure case looked good.

1945 Finished retrieval of Snubber. Headed to Standard SSAR estimated position.

2035 Visual sighting of Standard SSAR

2100 Began retrieval of Standard SSAR. All components look good.

2200 Ended retrieval, headed back to Biostation.

September 22, 1993

0130 Arrived at dock.

September 25-27, 1993

Packed equipment for shipment back to WHOI.

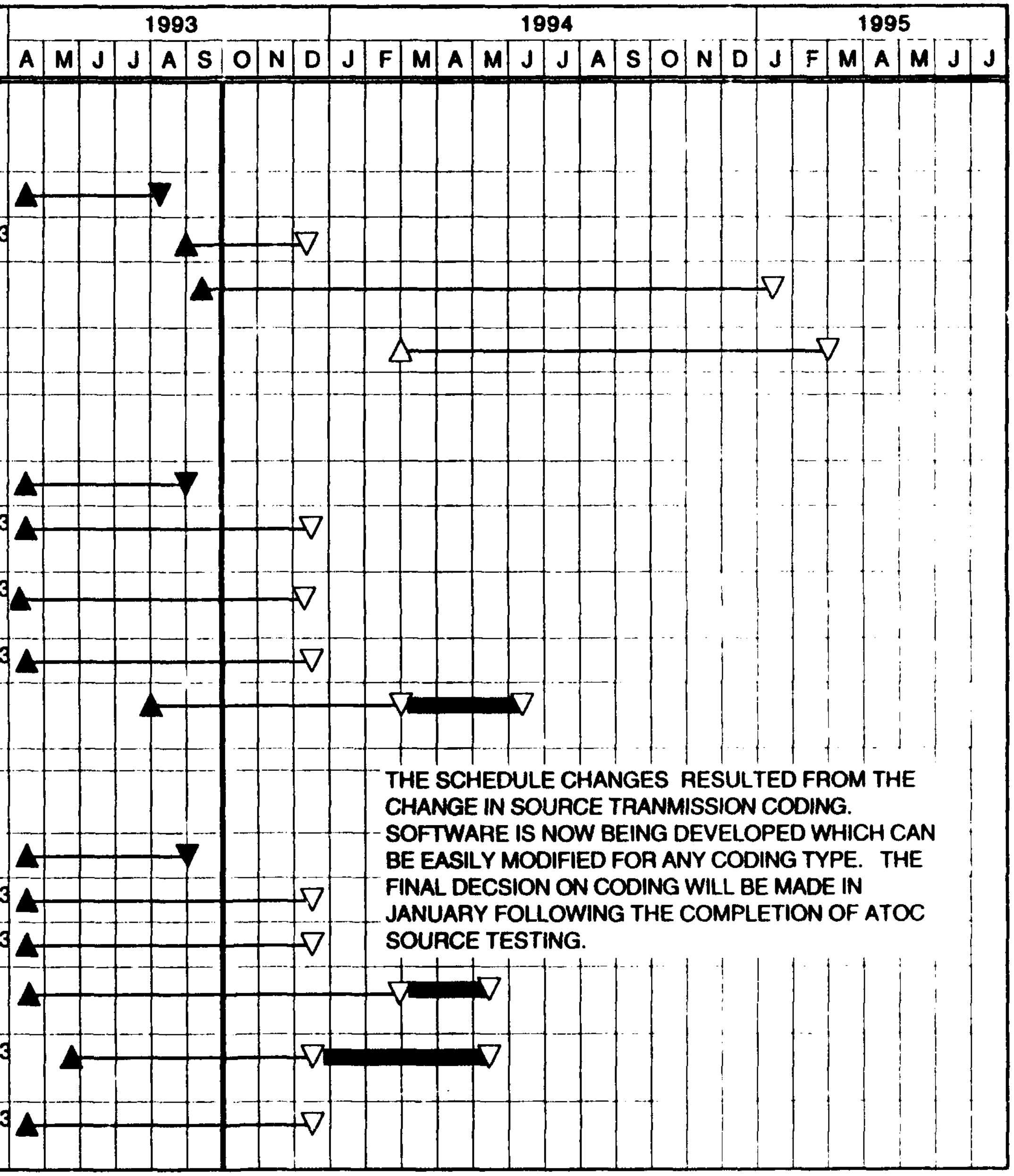
Snubber system and all electronics returned.

Standard system left in Bermuda for deployment in late October or early November.

Initial processing of SSAR recorded data showed that all systems appeared to work except Snubber hydrophone.

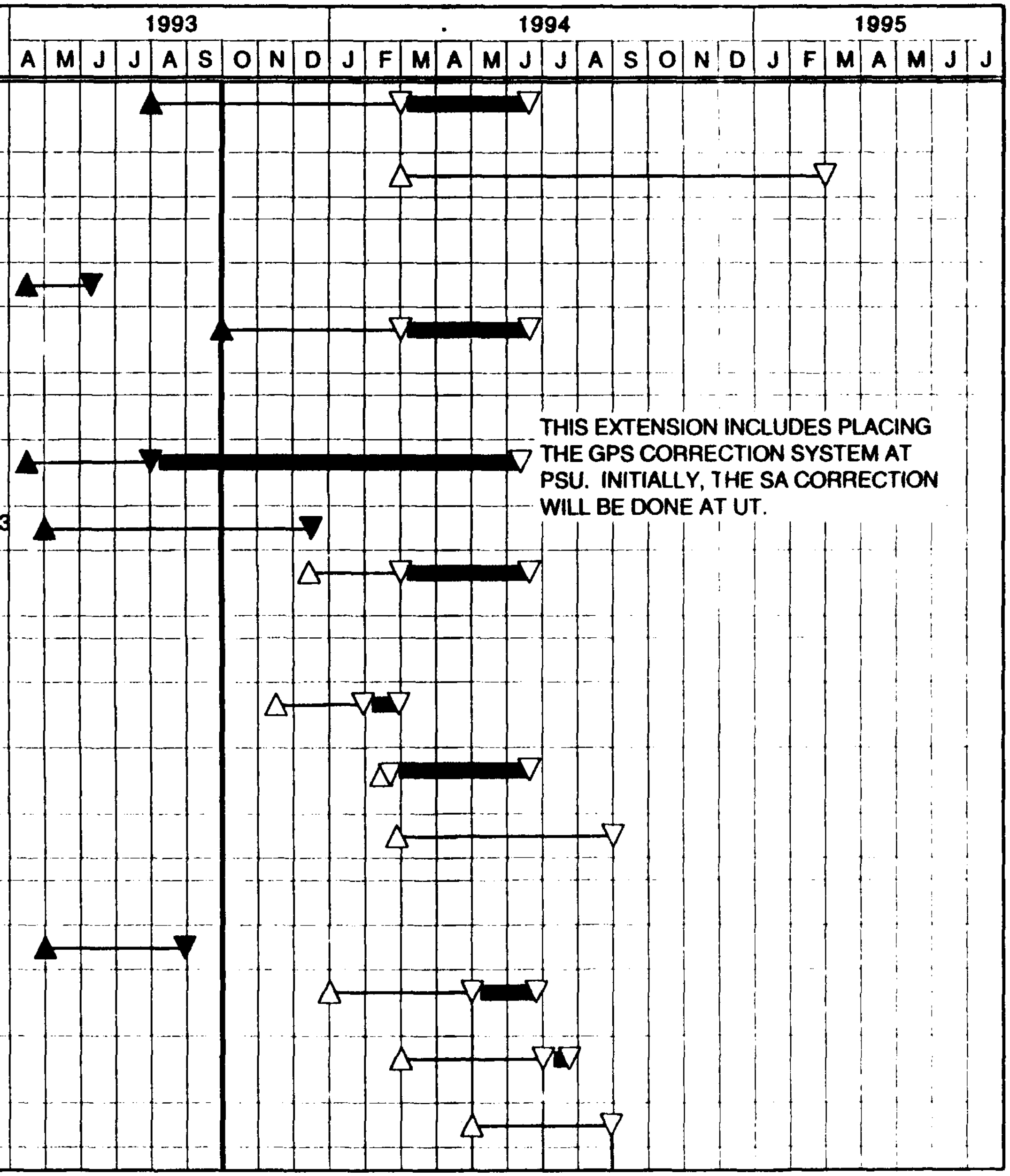
Initial decision on future tests is to instrument Standard SSAR with full suite of instruments for short term drift, then retrieve and re-deploy for a long-term drift test. The long-term test will rely on Argos telemetry for all data collection.

NUM	TASK C	Start Date	Finish Date
C.1	MECHANICAL DESIGN OF CABLE, BOUY AND TERMINATIONS		
	INITIAL DESIGN	4/15/93	8/9/93
	ACCEL LIFE TESTS	8/31/93	12/12/93
	AT SEA TRIALS	9/13/93	1/15/95
	DESIGN REFINEMENTS	3/1/94	3/1/95
C.2	BOUY ELECTRONICS AND NAV SYSTEMS		
	SYSTEM DESIGN	4/15/93	9/1/93
	CONTROLLER /GPS INTERFACE	4/15/93	12/15/93
	ARGOS TELEMETRY	4/11/93	12/11/93
	POWER SYSTEM	4/15/93	12/15/93
	PROTOTYPE TESTS	8/1/93 3/6/94	3/1/94 6/12/94
C.3	DSP SYS ACOUSTIC NAV AND SENSOR MODULE		
	SYSTEM DESIGN	4/15/93	9/1/93
	SENSOR MODULE	4/15/93	12/15/93
	ACOUS NAV MODULE	4/15/93	12/15/93
	DSP MODULE	4/18/93 3/6/94	2/27/94 5/15/94
	DSP SOFTWARE	5/23/93 12/26/93	12/15/93 5/15/94
	TELEMETRY	4/15/93	12/15/93



THE SCHEDULE CHANGES RESULTED FROM THE CHANGE IN SOURCE TRANMISSION CODING. SOFTWARE IS NOW BEING DEVELOPED WHICH CAN BE EASILY MODIFIED FOR ANY CODING TYPE. THE FINAL DECSION ON CODING WILL BE MADE IN JANUARY FOLLOWING THE COMPLETION OF ATOC SOURCE TESTING.

NUM	TASK C	Start Date	Finish Date
	PROTOTYPE TESTS	8/1/93 3/6/94	3/1/94 6/19/94
	DESIGN REFINEMENTS	3/1/94	3/1/95
C.4	HYDROPHONE ARRAY		
	ARRAY DESIGN	4/15/93	6/10/93
	PROTOTYPE TESTS	10/1/93 3/6/94	3/1/94 6/19/94
C.5	GPS NAV SA CORRECTIONS		
	DATA COLLECTION METHODS	4/15/93 8/8/93	8/1/93 6/12/94
	DEVELOP SOFTWARE	5/1/93	12/15/93
	PROTOTYPE TESTS	12/15/93 3/6/94	3/1/94 6/19/94
C.6	SYSTEM INTEGRATION		
	LAB TESTS	11/15/93 2/6/94	1/30/94 2/27/94
	AT SEA TEST	2/13/94 2/27/94	2/20/94 6/19/94
	DESIGN REFINEMENTS	2/25/94	9/1/94
C.7	FABRICATION OF SSAR		
	BUILD 2 PROTOTYPES	5/1/93	8/30/93
	BUILD & TEST 3 SSARS	1/1/94 5/8/94	4/30/94 6/26/94
	BUILD & TEST 3 SSARS	3/1/94 7/10/94	6/30/94 7/24/94
	BUILD & TEST 4 SSARS	5/1/94	8/30/94



NUM	TASK C	Start Date	Finish Date
C.8	FIELD OPERATIONS		
	DEPLOY 3 SSARS	5/1/94 6/5/94	5/30/94 7/3/94
	DEPLOY 3 SSARS	7/1/94 7/10/94	7/30/94 8/21/94
	DEPLOY 4 SSARS	9/1/94 9/18/94	9/30/94 10/30/94

1993: A M J J A S O N D — 1994: J F M A M J J A S O N D — 1995: J F M A M J J

WHILE IT IS POSSIBLE TO KEEP TO THE ORIGINAL DEPLOYMENT SCHEDULE FOR SSARs 4 THROUGH 10, A SIX WEEK SEPARATION BETWEEN DEPLOYMENTS IS CONSIDERED PRUDENT TO PROVIDE TIME TO OBSERVE THE PERFORMANCE OF SSARs 1 THROUGH 3.

TASK D
THE AUTONOMOUS MOORING

The autonomous mooring work has been delayed because a source has not yet been identified for the mooring to complete this important aspect of GAMOT's work. Our original understanding was that the long term source being developed under the ATOC program was envisioned as an appropriate source for the autonomous mooring by ARPA. However, it became clear, following the June program meeting in Seattle, that the long term source would not be available in time to meet our schedule for Task D. Additionally the design of the long term source may not be appropriate for an autonomous mooring.

ARPA directed WHOI to research the availability of a source which could be moored autonomously and to submit their findings to ARPA as well as identify the optimal course of action. WHOI developed a preliminary specification for this acoustic source considering minimum cost/schedule impact and requested budgetary pricing and delivery schedule information on August 23, 1993. The responses were presented to ARPA representatives on October 13, 1993 and on October 15, ARPA directed the GAMOT Principal Investigators to submit a proposal to increase the scope of Task D and gave the following guidelines:

- the frequency of the source will be 70 Hz.
- the schedule could be extended to accommodate the additional engineering and source procurement lead time.
- consider sources capable of transmitting m-sequences and FM codes.
- initially a dual design study could be undertaken.
- the proposal should contain go/no-go milestone decision points to ensure effective funding control.
- more than one option for each type of coding may be submitted along with recommendations as to the best course of action to follow.

The proposal will be completed in January 1994 and submitted to ARPA for approval. A revised schedule, milestones and deliverables which reflect the increased scope of Task D will be included in the next quarterly report.

ISSUES AND CONCERNS

In the previous quarterly report there were two issues which were addressed:

- Acoustic interaction of cabled sources with the bottom slope on which they are mounted, and
- Lack of an acoustic source for the autonomous mooring.

These issues have not been resolved and their current status will be addressed here.

There are no new issues.

CABLED SOURCES ON THE BOTTOM

As previously identified by the GAMOT Principal Investigator, bottom interaction may be a problem for the SSARs because the transmission paths change for each different SSAR position and the bottom interactions are typically not known well enough to accurately predict its effects. The Kauai and Pt. Sur sources will be bottom mounted. Detailed bottom surveys of the source locations have been conducted as part of the ATOC program. The GAMOT Program Manager has requested that survey information from ATOC. This information will be used to develop an analytical understanding of the expected bottom interactions prior to the deployment of the SSARs.

In March 1994, a prototype SSAR will be tested in the Pacific using the Kauai and Pt Sur sources. In preparation for this test, the signal reception data from all of the west coast ATOC receivers (SOSUS station and ATOC VLAs) has been requested from ATOC. Transmissions are currently scheduled to begin in February 1994. It is essential that GAMOT study the receptions of these ATOC receivers to investigate signal to noise ratios, stability of multipaths, and possible bottom interactions.

At the October 15 meeting of the GAMOT Executive Committee, ARPA agreed that if the effects of bottom interaction are significant and cause major signal reception problems for the SSAR, then the Executive Committee will review options to test the SSAR using a source which is free of bottom interaction.

IDENTIFICATION OF A SOURCE FOR THE AUTONOMOUS MOORING: TASK D

The autonomous mooring work is delayed because a source has not been identified for the mooring and the long term source is not appropriate to complete this important aspect of GAMOT's work prior to June 30,1995.

ARPA directed WHOI to research the availability of a source which could be moored autonomously and to submit their findings to ARPA as well as identify the optimal course of action. WHOI developed a preliminary specification for this acoustic source considering minimum cost/schedule impact and requested budgetary pricing and delivery schedule information on August 23, 1993. The responses were presented to ARPA representatives on October 13, 1993 and on October 15, ARPA directed the GAMOT Principal Investigators to submit a proposal to increase the scope of Task D and gave the following guidelines:

- the frequency of the source will be 70 Hz.
- the schedule could be extended to accommodate the additional engineering and source procurement lead time.
- consider both m-sequence and FM coding sources.
- initially a dual design study could be undertaken.
- the proposal should contain go/no-go milestone decision points to ensure effective funding control.
- more than one option for each coding source may be submitted along with recommendations to the best course of action to follow.

The preparation of that proposal has begun.

DELIVERABLES

Three deliverables were due and delivered this quarter:

- The coastal Kelvin signal was extracted from the equatorial model and used to drive the mid-latitude model from 1980-1990. *Figures are contained in* the Task B section and a video was provided to ARPA.
- A graph of travel time difference as a function of time and the geodesic path based on model solutions between the Hawaii and West Coast receivers was provided to ARPA.
- Two prototype SSARs were delivered.

Four deliverables are due during the next quarter:

- GAMOT's recommendation for the optimal source frequency, location, depth and type.
- The range of the acceptable depths for the SSAR.
- A progress report on the connection between the observed acoustic data and the ocean climate model.
- A SSAR progress report.

Figure:
Fig. 1 GAMOT Deliverable Master Schedule

TASK	DELIVERABLE	Start Date	1993 J	J	A	S	O	N	D	1994 J	F	M	A	M	J	J	A	S	O	N	D	1995 J	F	M	A	M	J	J	A
A.1	SOURCE DEPTH, FREQ, LOCATION AND TYPE RECOMMENDATION	11/30/93						◇																					
A.2	RANGE OF ACCEPTABLE SSAR DEPTHS	11/30/93						◇																					
A.3	SIGNAL PROCESSING OF SSAR SIGNAL	6/30/95																									◇		
A.4	ARRAY MOTION COMPENSATION SOFTWARE	3/30/94										◇																	
A.5	SEASONAL MULTIPATH ALGORITHMS	6/30/95																									◇		
A.6	ARGOS RECEPTION ERROR STUDY	6/30/95																									◇		
A.7	ALTERNATIVE SATELLITE SYSTEM EVALUATION	6/30/95																									◇		
A.8	REAL TIME TOMOGRAPHY ALGORITHMS	6/30/95																									◇		
A.9	NEW WORK: SEASONAL CYCLE INFLUENCES ON ACOUSTIC TRAVEL TIMES BASED ON ANALYSIS OF 1987 TOMO DATA	8/30/94															◇												
A.10	NEW WORK: OCEAN MODEL OF TEMPERATURE MAPPING USING SSARS	5/30/95																								◇			
B.1	1980-1991 EQUATORIAL WIND FIELD MODEL STATEMENT OF COMPLETION	6/30/93	◆																										
B.2	EXTRACT THE COASTAL KELVIN SIGNAL FROM THE EQUATORIAL MODEL AND DRIVE THE MID-LATITUDE MODEL FROM 1980-1990 AND PROVIDE A VIDEO OF THE SOLUTION	9/30/93				◆																							

TASK	DELIVERABLE	Start Date
B.3	INTEGRATE THE MODEL SOLUTIONS BETWEEN HAWAII AND WEST COAST RECEIVERS AND PROVIDE A GRAPH OF TRAVEL TIME DIFFERENCE AS A FUNCTION OF TIME AND GREAT CIRCLE PATH	9/30/93
B.4	DRAFT PAPER (AND PROGRESS REPORT) DEMONSTRATING CONNECTION BETWEEN OBSERVED ACOUSTIC DATA AND OCEAN CLIMATE MODEL	12/30/93
B.5	PROVIDE DETAILED PLAN FOR IMPLEMENTING INVESTIGATION FOR MORE COMPLICATED MODELS. PROVIDE PROTOTYPE DESIGN OF EXPERIMENT FOR MONITORING THE NORTH PACIFIC FOR CLIMATE CHANGE AND NATURAL VARIABILITY	6/30/94
B.6	DOCUMENT RAY TRACING PROGRAMS USED IN OCEAN PHYSICAL MODELING	12/30/94
B.7	REPORT ON THE ANALYSIS OF THE RUN OF 1970-1991 NRL MODELS	5/30/95
B.8	IMPLEMENT DATA ASSIMILATION PLAN USING ADJOINT MODEL	5/30/95
B.9	FINAL REPORT EXPLAINING OR NOT EXPLAINING OBSERVED CLIMATE VARIABILITY IN THE NORTH PACIFIC OCEAN	6/30/95

TASK	DELIVERABLE	Start Date
C.1	SSAR PROGRESS REPORT	11/30/93
C.2	SSAR DES[illegible]N AND TEST REPORT	4/30/94
C.3	SSAR UPDATED DESIGN REPORT	3/30/95
	SSAR DELIVERIES	
C.4	TWO PROTOTYPES	8/30/93
C.5	SSARs 1 THRU 3	4/30/94 5/8/94
C.6	SSARs 4 THRU 6	6/30/94 7/10/94
C.7	SSARs 7 THRU 10	8/30/94 9/11/94
	CRUISE REPORTS	
C.8	DEPLOY SSARs 1-3	6/30/94
C.9	DEPLOY SSARs 4-6	8/30/94
C.10	DEPLOY SSARs 7-10	10/30/94
C.11	SSAR FINAL REPORT	6/30/95
D.1	70 HZ SOURCE ASSESSMENT	
D.1	MOORING FABRICATION REPORT	
D.2	AUTONOMOUS MOOR AT SEA TEST AND CRUISE REPORT	
D.3	MOORING DEPLOYMENT CRUISE REPORT	
D.4	MOORING MAINTENANCE CRUISE REPORT	

SEE THE TASK C SECTION FOR AN EXPLANATION OF THESE SCHEDULE CHANGES.

ALL TASK D DELIVERABLES WILL BE RESCHEDULED FOLLOWING THE APPROVAL OF THE PROPOSAL TO INCREASE THE SCOPE OF THIS TASK TO INCLUDE PROCUREMENT OF A 70 Hz SOURCE.

TASK	DELIVERABLE	Start Date	1993							1994												1995							
			J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
E.1	DARPA COORDINATION MEETINGS AND PROGRAM BRIEFS	5/20/93 6/7/93 7/1/93 9/16/93 10/15/93 3/18/94	◆	◆		◆	◆					◇																	
E.2	QUARTERLY PROGRESS REPORTS	7/15/93 10/15/93 1/15/94 4/15/94 7/15/94 10/15/94 1/15/95 4/15/95		◆			◆			◇			◇			◇			◇			◇			◇				
E.3	FINAL PROJECT REPORT	6/30/95																									◇		
F.1	TRANSITION PLAN IMPACT REPORT	6/30/95																									◇		
F.2	LONG TERM PROGRAM INPUT REPORT	6/30/95																									◇		
F.3	LONG TERM PROGRAM RISK ANALYSIS REPORT	6/30/95																									◇		